

Technical Report 899

AD-A226 129



# Designing a Gunnery Training Strategy

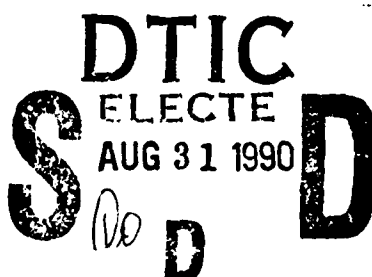
**John E. Morrison**

Human Resources Research Organization

**Dennis H. Holding**

University of Louisville

**June 1990**



**United States Army Research Institute  
for the Behavioral and Social Sciences**

Approved for public release; distribution is unlimited

90 03 20 204

# **U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES**

**A Field Operating Agency Under the Jurisdiction  
of the Deputy Chief of Staff for Personnel**

**EDGAR M. JOHNSON**  
Technical Director

**JON W. BLADES**  
COL, IN  
Commanding

---

Research accomplished under contract  
for the Department of the Army

Human Resources Research Organization

Technical review by

David W. Bessemer  
Scott E. Graham

## **NOTICES**

**DISTRIBUTION:** Primary distribution of this report has been made by ARI. Please address correspondence concerning distribution of reports to: U.S. Army Research Institute for the Behavioral and Social Sciences, ATTN: PERI-POX, 5001 Eisenhower Ave., Alexandria, Virginia 22333-5600.

**FINAL DISPOSITION:** This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

**NOTE:** The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

## REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS ---	
2a. SECURITY CLASSIFICATION AUTHORITY ---			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE ---				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) FR-PRD-90-12			5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Technical Report 899	
6a. NAME OF PERFORMING ORGANIZATION Human Resources Research Organization	6b. OFFICE SYMBOL (If applicable) ---	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences		
6c. ADDRESS (City, State, and ZIP Code) 1100 S. Washington Street Alexandria, VA 22314		7b. ADDRESS (City, State, and ZIP Code) ARI Field Unit--Fort Knox ATTN: PERI-IK Fort Knox, KY 40121-5620		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences	8b. OFFICE SYMBOL (If applicable) PERI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAHC35-89-C-0009		
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600		10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO. 62785A	PROJECT NO. 790	TASK NO. 3205
		WORK UNIT ACCESSION NO. C1		
11. TITLE (Include Security Classification) Designing a Gunnery Training Strategy				
12. PERSONAL AUTHOR(S) Morrison, John E. (HumRRO); Holding, Dennis H. (University of Louisville)				
13a. TYPE OF REPORT Final	13b. TIME COVERED FROM 89/09 TO 90/01	14. DATE OF REPORT (Year, Month, Day) 1990, June	15. PAGE COUNT	
16. SUPPLEMENTARY NOTATION Contracting Officer's Representative, Donald F. Haggard				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Armor training	
			Gunnery training	
			Training strategies	
			Training devices	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report is one in a series that examines the development of research tools to support this research. The focus of this research was to develop methods for designing a gunnery training strategy. A training strategy was defined as any method for configuring instruction to enhance learning and/or reduce training costs. However, this report was limited to the discussion of methods that address the following key functions of training strategies: (a) organizing training objectives into units of instruction, (b) sequencing training both within and among units of instruction, (c) selecting the appropriate training device or medium for each unit, and (d) allocating training time to each unit/device combination. The training strategy methods were first discussed in terms of their theoretical rationale and usefulness for gunnery training. The methods were then tested by applying them to two prototypical problems in gunnery training: (1) the use of two different devices for training similar basic gunnery skills, and (2) the use of multiple devices to train the dissimilar skills in platoon gunnery. The application of methods for designing a training (Continued)				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Donald F. Haggard			22b. TELEPHONE (Include Area Code) (502) 624-3450	22c. OFFICE SYMBOL PERI-IK

ARI Technical Report 899

## 19. ABSTRACT (Continued)

strategy demonstrated, in general, that the various methods can be applied to dissimilar gunnery training problems with sensible results. Only one of the methods failed to apply to both problems--the methods for allocating training time were not able to handle the more difficult multi-device tactical training problem.

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A-1	

**Technical Report 899**

## **Designing a Gunnery Training Strategy**

**John E. Morrison**

Human Resources Research Organization

**Dennis H. Holding**

University of Louisville

**Field Unit at Fort Knox, Kentucky**

**Donald F. Haggard, Chief**

**Training Research Laboratory**

**Jack H. Hiller, Director**

U.S. Army Research Institute for the Behavioral and Social Sciences

5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel

Department of the Army

**June 1990**

---

**Army Project Number**  
**2Q162785A790**

**Human Performance Effectiveness**  
**and Simulation**

*Approved for public release; distribution is unlimited.*

## FOREWORD

---

The Army has a continuing research need to investigate the effects of and tradeoffs among alternative devices and strategies for training gunnery skills. This report is one in a series that concerns the development of research tools for supporting such research. Previous work in this series has described the development and application of methods for determining valid threat engagement scenarios for training gunnery skills, and methods for identifying gunnery training objectives that may be trained in those engagement scenarios. In other words, the previous work has established what is to be trained. In contrast, the focus of this report is on how the objectives should be trained. The specific purpose of this report is to describe and apply methods that address four central problems that impact the design of gunnery training: the organization of training objectives into units of instruction, the sequence of training both within and among units of instruction, the selection of an appropriate training device or medium for each unit, and the allocation of training time to each unit/device combination.

The methods described in this report represent significant contributions to the Army Research Institute for the Behavioral and Social Sciences (ARI) Exploratory Development research program. The audience for this report includes scientists who perform research related to the evaluation of training strategies and devices. However, these same methods should also be of interest to those who develop actual military training. This research is part of the ARI task entitled "Application of Technology to Meet Armor Skills Training Needs." It is performed under the auspices of ARI's Armor Research and Development Activity at Fort Knox. The proponent for the research is the Deputy Chief of Staff, Training, U.S. Army Training and Doctrine Command.



EDGAR M. JOHNSON  
Technical Director

## DESIGNING A GUNNERY TRAINING STRATEGY

### EXECUTIVE SUMMARY

---

#### Requirement:

The Army has a continuing research need to investigate the effects of and tradeoffs among alternative devices and strategies for training gunnery skills. This report is one in a series that concerns the development of research tools for supporting such research. Previous research in this series defined the context and the content of crew- and platoon-level gunnery training. The purpose of the present research was to develop and apply strategies for training gunnery skills.

#### Procedure:

A training strategy was defined as a method for systematically configuring training events. To apply the concept of training strategies to the design of armor gunnery training, strategies were further distinguished by four general problems that they address (a) the derivation of an appropriate structure that identifies units of instruction, (b) the sequencing of training both within and among units of instruction, (c) the selection of an appropriate training device or medium for each unit, and (d) the allocation of training time to each unit/device combination. The training strategy methods were first discussed in terms of their theoretical rationale and their usefulness for gunnery training. The methods were then tested by applying them to two prototypical problems in gunnery training. The first problem addressed the use of two different devices for training similar basic gunnery skills, whereas the second problem concerned the use of multiple devices to train dissimilar skills in platoon gunnery.

#### Findings:

The application of methods for designing a training strategy demonstrated, in general, that the various methods could be applied to dissimilar gunnery training problems with sensible results. Only one of the methods failed to apply to both problems. The methods for allocation of training time were only applicable to the simpler gunnery training problem where only two training devices were considered; the methods for allocating training time were not able to handle the more difficult multi-device tactical training problem. Some of the other problems were also noted relating to the fact that some of the methods are not as fully developed as others; that is, they were stated as heuristic guidelines rather than as fully developed algorithms.

### Utilization of Findings:

The methods discussed in the present report are primarily intended for use by scientists who perform research related to the evaluation of training strategies and devices. However, these same methods should also be of interest to those who develop actual military training. Furthermore, although the methods of the present report were tested on armor skills, the training strategies should nevertheless apply to training in any combat arm.



# DESIGNING A GUNNERY TRAINING STRATEGY

## CONTENTS

---

	Page
INTRODUCTION . . . . .	1
Previous Research in This Series . . . . .	1
Training Strategies . . . . .	2
Specific Objectives and Report Organization . . . . .	3
METHODS FOR DESIGNING A TRAINING STRATEGY . . . . .	3
Structure Training . . . . .	5
Sequence Training . . . . .	11
Select Media/Devices . . . . .	22
Allocate Training Time . . . . .	27
APPLICATION OF TRAINING STRATEGY METHODS . . . . .	37
Training Similar Skills with Different Devices: Using VIGS and I-COFT to Train Target Engagement Skills . . . . .	37
Training Dissimilar Skills with Dissimilar Devices: Using Various Devices to Train Platoon-Level Gunnery Skills . . . . .	44
Summary and Conclusions . . . . .	61
REFERENCES . . . . .	63
APPENDIX. METHODS AND MATERIALS FOR STRUCTURING AND SEQUENCING TRAINING . . . . .	A-1

## LIST OF TABLES

Table 1. Principles of sequencing . . . . .	13
2. Asymmetric transfer versus training sequence . . . . .	18
3. Summary of sequencing rules . . . . .	22
4. Summary of to-be-trained subtasks and device capabilities . . . . .	39
5. Findings from hypothetical research measuring transfer from VIGS to I-COFT . . . . .	44
6. Platoon collective subtasks . . . . .	45
7. Descriptions of training devices with respect to fidelity attributes . . . . .	49

## CONTENTS (Continued)

---

	Page
Table 8. Weights of fidelity attribute for platoon-level subtasks . . . .	50
9. Application of sequencing principles at higher levels of the hierarchy . . . . .	57
10. Assignment of devices to tasks in clusters . . . . .	58
11. Task orders resulting from successive modifications within clusters . . . . .	59
12. Final orders for subtasks within all platoon collective tasks . . . . .	60
13. Training recommendations using ordered subtasks with assigned device support . . . . .	61

## LIST OF FIGURES

Figure 1. Comparison of transfer indexes derived by Roscoe (CTER) and Holding (total hours) . . . . .	29
2. Components of the total cost function . . . . .	31
3. Summary of structure and sequencing strategy for using VIGS and I-COFT to train gunnery engagement . . . . .	42
4. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to travel . . . . .	51
5. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to positions . . . . .	51
6. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to drills . . . . .	52
7. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to firing . . . . .	52
8. Hierarchical arrangement of platoon collective subtasks . . . .	55

## DESIGNING A GUNNERY TRAINING STRATEGY

### Introduction

The Army has a continuing research need to investigate the effects of and tradeoffs among alternative devices and strategies for training gunnery skills. The present report is one in a series that concerns the development of research methods and tools for supporting this research. The purpose of the present report is to derive training strategies that are designed to enhance tank gunnery training, and to demonstrate their application on some representative problems in gunnery training. These strategies serve both primary and secondary functions. The primary function of these strategies is to provide guidance for development of experimental training procedures and materials required to examine other research issues, for example, the derivation of skill acquisition and transfer functions. This guidance is based on the current learning theory and findings from the literature. The strategies themselves range from well known methods that are supported by a wealth of data to theoretically plausible methods that are supported by limited findings. Strategies on the latter end of the spectrum can provide the focus for further research. Thus, the secondary function of training strategies is to generate testable hypotheses about the conduct of gunnery training.

### Previous Research in This Series

Previous work in the series on gunnery research has described the development and application of methods for determining valid threat engagement scenarios for training gunnery skills (R. Campbell & C. Campbell, 1990; Doyle, 1990), and methods for identifying gunnery training objectives that may be trained in those engagement scenarios. These threat scenarios described key engagements that are likely to occur within the context of the execution of various Red (threat) and Blue (friendly) mission combinations. The detailed scenario information included the specification of the number, type, and range of likely threat vehicles. In summary, this initial research established the context for gunnery training and performance measurement.

A subsequent report in the series (Morrison, Meade, & Campbell, 1990) was concerned with the development and application of methods for determining training objectives that are appropriate to these scenarios. Objectives were defined as subtasks performed at crew or platoon level. Cluster analyses of the crew-level objectives indicated eight distinct categories of subtasks, the largest of which were continuous control, psychomotor subtasks related to manipulation of control handles in both machine gun and main gun engagements. Other categories of subtasks related to topics such as (a) the control of gunnery engagements by the tank commander, (b) target acquisition, (c) immediate action procedures, (d) switch setting procedures, (e) fire commands and reporting duties, (f) decisions and actions related to operation in degraded modes, and (g) tank maneuvering skills. At the platoon level of analysis, two types of subtasks were identified: (a) individual platoon leadership subtasks, cognitive/verbal actions related to platoon coordination both internal and external; and (b) platoon collective subtasks, actions characterized by the predominance of interactive and coordinative skills. In

short, this analysis indicated that the contents of gunnery training consist of an extensive and heterogeneous set of training objectives.

### Training Strategies

Having established the context for and the contents of a gunnery training program, the next step in training development was to specify how training should be configured. We use the term "training strategy" to differentiate the consideration of this aspect of training development apart from the specification of training context and content. There are a wide variety of training strategies that could be applied to specific training objectives. For example, Morrison and Walker (1989) applied mental practice techniques to learning the procedural and psychomotor skills related to gunnery. There are far too many of these types of specific strategies to comprehensively review in one report. Furthermore, these specific strategies are limited by their restricted range of applications.

In contrast to the numerous specific strategies mentioned in the previous paragraph, there is a smaller number of more broadly defined strategies which are designed to apply across dissimilar types of objectives. These latter types of training strategies are defined as instructional methods that address some general problems of training design. One problem in providing a precise definition of a "training strategy" is that researchers have used the term to refer to methods that apply to one or maybe two of these general problems to the exclusion of methods that apply to the other problems. To develop a definition of a "training strategy" that is relevant to gunnery training needs, it is useful to first identify the types of general problems that are particularly troublesome for gunnery training. These problems serve to define the components of a comprehensive strategy for training gunnery skills.

The training development literature identifies strategies related to two different but related problems: determining the appropriate structure and determining the appropriate sequence of training (Reigeluth & Curtis, 1987). The structure of training refers to the organization of individual objectives into instructional units that serve as the targets of training design. The sequence of training refers to a prescription of the order in which the objectives should be addressed, both within and among instructional units. The two problems are related because they both relate to the configuration of training. For a small number of homogeneous objectives, the appropriate configuration may be obvious to the training developer. However, the domain of gunnery training objectives is neither small nor homogeneous. Given the nature of the domain of gunnery training objectives, systematic strategies are required to structure and sequence training.

Training managers and developers in the Armor community commonly use "training strategy" to refer to methods for addressing the problem of selecting training devices or media. The problem of selecting training devices is particularly acute for armor training given the number of devices that address gunnery skills. Hoffman and Morrison (1988) identified four computer-based devices that could be used to train gunnery skills. Analysis of device capabilities indicated substantial overlap in the training functions of devices. The decision that the training developer must make is to choose the device that is appropriate for a particular skill and that also conforms to the structure and sequence of the course. To the computer-based devices

addressed by Hoffman and Morrison, the present report adds a variety of new tank-appended technologies for training crew- and platoon-level skills, thereby complicating the device selection problem. Thus, device selection methods are key components to a gunnery training strategy.

Researchers who specialize in the effects of training devices (e.g., Roscoe & Williges, 1980) have used training strategies to refer to methods that apply to yet another problem in training design: the allocation of training time between a training device and the actual equipment. More generally stated, this type of training strategy refers to allocation of training time among all training media, including the operational equipment. The purpose of this training strategy is to allocate training time such that performance is maximized or that training costs are minimized. This particular training strategy is important for gunnery training because of the device alternatives differ in terms of their effectiveness to train certain objectives, and in terms of the costs associated with delivering that training. Thus, the allocation strategy must consider both factors (training effectiveness and costs) in determining appropriate training times for devices.

In summary, training strategies can be discussed in the context of four general problems that seriously impact the design of gunnery training: (a) the derivation of an appropriate structure that identifies units of instruction, (b) the sequencing of training both within and among units of instruction, (c) the selection of an appropriate training device or medium for each unit, and (d) the allocation of training time to each unit/device combination. Any comprehensive gunnery training strategy must address all of these fundamental problems.

### Specific Objectives and Report Organization

The purpose of the present report is to describe and to apply training strategies that address the four aforementioned problems. The report is divided into two major sections. The first section describes the methods for designing training strategies by presenting their theoretical rationale and evaluating their usefulness for gunnery training; thus, it is referred to as the "methods" section. The second section presents the same methods in a more applied context by discussing them in the context of two prototypical problems in gunnery training; thus, the second section is referred to as the "applications" section.

### Methods for Designing a Training Strategy

Many methods related to the design of training strategies are compiled in the Interservice Procedures for Instructional Systems Development (ISD) (Branson et al., 1975). While some of the ISD procedures serve as useful points of departure, the present review concentrates on methods that have emerged during the 15 years since the publication of that influential document. It should be noted at the outset that the methods described in the present report were not derived from a single theoretical point of view. Rather, they comprise an eclectic group of methods that were selected because they were logical, practicable, and/or supported by empirical findings.

This present section presents a wide array of methods for designing training strategies--some of which are well-known, others have been developed specifically for the present project. Despite the diversity of methods, each can be described as being either algorithmic or heuristic. Apter (1970) defines an algorithm as an ". . . unambiguously stated 'machine-like' procedure which, if followed literally, will inevitably achieve the intended result" (p. 40). Arithmetic procedures (e.g., adding, subtracting, multiplying, or dividing) or computer programs are examples of algorithmic methods. Simple algorithms can be described as a series of sequential steps, while more complex branching algorithms are better described in terms of flowcharts. An example of an algorithmic method for specifying training strategies is the set of learning guidelines presented in the Interservice Procedures for Instructional Systems Development (Branson et al., 1975). These guidelines were presented as a set of algorithms for prescribing the learning activities that should occur during training. The particular algorithm used depends on the category of information processing that is most characteristic of the task(s) being trained, for example, rule learning/using, classifying/recognizing, identifying symbols, and performing gross motor skills.

In contrast to an algorithm, a heuristic is ". . . a set of rules which, if followed, may achieve a solution but cannot guarantee to do so" (Apter, 1970, p. 83). The instructional sequencing procedure described by Branson et al. (1975) is an example of a heuristic method that is embodied as a loosely defined set of rules. For instance, one of their rules (critical sequence) states that learning objectives should be ordered from most to least important. Another (simple to complex) states that objectives should be ordered in terms of increasing complexity. To see how these guidelines apply, consider two gunnery subtasks identified by Morrison et al. (1990): lase to target and fire at target. Firing at the target is clearly the more critical subtask of the two in terms of accomplishing the overall task goal, that is, to hit the target. On the other hand, lasing is more complex because the gunner is not only required to hit the target (with a laser beam, not a round), but the gunner must also evaluate the laser return quickly to decide whether to lase again or go ahead and fire at the target. Because these two rules lead to contradictory conclusions, the solution (i.e., the instructional sequence for these two objectives) cannot be determined from these two heuristics alone.

Superficially, algorithmic methods appear more rigorous than heuristic methods. Indeed, one could argue that algorithmic formats should be the eventual goal in the methodological development of training strategies. Given the present state of knowledge about training, however, heuristic guidelines are often the only realistic type of prescription that may be provided to training designers. Furthermore, algorithms can be crippled by unrealistic simplifying assumptions that reduce their range of applicability. For instance, the training prescription algorithms presented by Branson et al. (1975) apply to only 11 categories of tasks. Thus, this algorithmic approach tacitly assumes that tasks can be reliably sorted into mutually exclusive learning categories--an assumption that has been challenged on a number of fronts (e.g., Boldovici, Harris, Osborn, & Heinecke, 1977; Vineberg & Joyner, 1980). Another drawback to mathematical algorithms is that necessary input data may not be available and may be difficult to generate. For instance, the methods for allocating training time are based on determining transfer

functions. As is discussed later in this methods section, the data collection requirements for obtaining the transfer data are not trivial.

The following descriptions of training strategy methods are organized according to the four general problems identified in the Introduction: (a) structure training, (b) sequence training, (c) select media, and (d) allocate training time. It should be noted that the four groups of methods differ with respect to the characteristics discussed above. The methods associated with the first two problems (structuring and sequencing training) are heuristic in nature; that is, the methods are basically guidelines to training design rather than explicit procedures. The appendix presents an attempt to develop the methods further by formalizing the use of those guidelines. Although the methods for structuring and sequencing training are not well developed, their execution requires only knowledge of training methods and the objectives themselves. In contrast, the methods related to the latter two problems (selecting media and allocating training time) are based on computational algorithms that are quite well developed. On the negative side, the data for executing these algorithms are more difficult to obtain. After the description of each training strategy method, a brief evaluation of the method is offered. In some cases, the evaluation summarizes the research literature for and against the methods. In other cases, empirical research is proposed to resolve methodological problems.

### Structure Training

There are two purposes that are commonly cited for structuring or organizing training. The ISD documentation (Branson et al., 1975) points out that one purpose of structuring training is to facilitate the development and implementation of training by creating independent "modules" of instruction. This first purpose implies that the structure of training depends on practical considerations such as administrative convenience and media availability. While it is clear that these factors are important to the structuring process, it is also clear that these factors are specific to particular training applications. The second, and perhaps more fundamental, purpose for structuring training is to promote the acquisition, retention, and transfer of gunnery skills. The following review focuses on factors that relate to this second purpose for structuring.

The process of structuring training requires the identification of relationships that exist among training objectives. The following sections discuss two types of possible relations that may exist among objectives and that affect skill acquisition. The first section provides a discussion of the concept of dependent and supportive relations among objectives--traditional concepts in the training development literature. These types of relations correspond to the concepts of learning prerequisites and transfer of training, respectively. In addition to implications for structuring training, these concepts also have implications for the order of training, and are consequently discussed in the context of the next problem (sequencing training). The second and third sections under the present problem focus on some newer concepts that have evolved from recent research on part-task training: the extent to which sequentially related subtasks address common task goals and the extent to which time-shared subtasks share similar attentional resources.

## Dependent and Supportive Relations

In the ISD procedures, Branson et al. (1975) distinguished between dependent and supportive relationships. A dependent relationship is defined wherever the learning of one objective is necessary in order to learn another. For instance, Morrison and Hoffman (1988) identified the skill of tracking armor gunnery targets as dependent on the more basic skill of knowing how to manipulate the gunner's control handle. In contrast, a supportive relationship is defined wherever the learning of one objective is helpful to (but not required for) learning the other. In other words, skills learned in the first objective transfer to the second. This latter sort of transfer relationship occurs because of similarities between objectives in their conditions and/or behaviors. For instance, the skills related to engaging main gun targets and engaging coax targets are not dependent upon one another. Nevertheless, the two types of skills are sufficiently similar to expect positive transfer from the learning of one type of engagement to the learning of the other.

Although dependent and supportive relationships may be conceptually distinguished from one another, their implications for a training strategy are similar: To the extent possible, related objectives should be kept in close proximity to one another. Dependently related objectives should be kept together to prevent the prerequisite skills of the dependent skill from being forgotten over time or through interference with other learning before learning the superordinate objective. Similarly, transfer between supportive objectives is maximized when objectives are located in close temporal proximity to one another such that forgetting and interference effects are minimized.

Methods. Dependent relationships are usually identified through rational, heuristic methods called hierarchical learning analysis of task prerequisites (e.g., Gagné, 1967; Resnick, 1976).<sup>1</sup> Hierarchical analysis starts by examining the terminal learning objective to identify prerequisite objectives, that is, those that are necessary for a student to learn before learning the terminal objective. Each prerequisite skill is then examined to determine whether or not lower level prerequisites need to be identified. This analysis stops when it reaches prerequisite skills that may be assumed to be possessed by all members of the to-be-trained populations. The results of the analysis are usually summarized by an inverted tree structure with the terminal training objective placed at the top of the tree with prerequisite relations represented as branches connecting prerequisites to the superordinate objective that they support.

Supportive relationships are usually identified through an analysis of the similarity of training objectives in terms of their stimuli and/or responses. Predictions of positive and negative transfer were summarized by Osgood's (1949) transfer surface, which was originally based on results from verbal and simple motor learning experiments. Holding (1976) modified this surface based on more recent results from the skill learning literature. Though different in their particulars, two key "principles" for predicting

---

<sup>1</sup>Hierarchical relationships are further examined in the next section in connection with the sequencing of training.



transfer can be derived from either surface: (a) positive transfer will occur between two tasks when their stimuli are similar and when their responses are similar; and (b) negative transfer will occur when the responses to the similar stimuli are different. Similar transfer principles are implicit in models that the Army has developed to predict the effectiveness of training devices. (For a review of these models, see Tufano & Evans, 1982).

Evaluation. Although there is scant evidence that organizing training with respect to dependent relationships actually promotes skill acquisition (e.g., White, 1973), this particular strategy is congruent with standard educational practice. Hoffman and Morrison (1988) applied hierarchical analysis techniques to examine gunnery training objectives. They found that gunnery does not have an elaborate structure of prerequisites. The lack of prerequisites implies that the number of dependent relationships in gunnery is probably limited.

With respect to supportive relationships, there is substantial evidence from the research literature substantiating the claim that amount or degree of transfer between tasks is a positive function of their similarity. The problem is in precisely defining similarity. Osgood's and Holding's transfer surfaces define similarity on the basis of task stimuli and responses. It should be noted that the generalizations from the transfer surface are largely based on findings from verbal paired associate learning where stimuli and response are well differentiated. In real-world psychomotor tasks such as those related to gunnery, stimuli and responses are not as distinguishable. Target tracking in gunnery provides a prototypical example. Initially, the response in tracking is to manipulate the gunner's control handle. The response input, however, feeds back into the system to change the sight picture (i.e., the visual stimuli) so that stimuli and response become highly intertwined. As a consequence, analysis by transfer surfaces would be difficult to apply directly to many armor skills.

#### Commonality in Subgoals

The process of dividing tasks into sequential parts for training has been termed segmentation (Naylor, 1962). Several researchers have suggested that segmentation should be congruent with the task subgoal structure (Hoffman, Drucker, Morrison, & Goldberg, 1983; Knerr et al., 1986; Morrison, 1984). That is, the "parts" for part training by segmentation should be behaviors related by the fact that they share a common task subgoal. For instance, Morrison showed that the sequential behaviors required to clear a machine gun could be related to one or the other of two task subgoals: unload the gun and return the bolt to the forward position. According to a segmentation strategy, this machine gun task should be partitioned for part-task training in accordance with those two goals.

Methods. Researchers have demonstrated that relationships among task behaviors and subgoals can be identified through either rational methods (i.e., task analytic) or an empirical analysis of performance. Morrison and Goldberg (1982) reviewed the cognitive literature to reveal guidelines for rationally parsing tasks into goals and subgoals. They applied these guidelines to the analysis of several armor procedures. In a follow-up study, Morrison (1984) described a procedure that was based on an empirical analysis of recall performance. This analysis of recall is based on Friendly's (1979)

assumption that items grouped together in memory tend to be recalled closely together. Thus, the organization of memory for a task can be derived from the pattern of interresponse times in free recall of the task elements. The two approaches to determining these relationships were mutually confirming in two senses: (a) the rational analysis aided in interpreting the results from the analysis of free recall, and (b) the proximity analysis of free recall confirmed and elaborated on the rational analysis of task subgoals.

Three recent studies on flight tasks (Bailey, Hughes, & Jones, 1980; Westra, 1982; Wightman, 1983) have demonstrated that part training by segmentation produces superior performance than training on the whole task. These studies rationally segmented complex flight tasks (30° dive bomb for the former, carrier landing for the two latter studies) into sequential segments. Part training using a recombination procedure called "backward chaining" (see section on sequencing training) was successful in producing greater learning than equivalent amounts of whole task learning.

Although these findings support the rule to group behaviors related by common subgoals, the demonstrated difference between part and whole training could be predicted from other theoretical points of view. In fact, part training of complex and difficult tasks is appealing and predictable from the layman's point of view (Adams, 1960). A more direct test of the effects of subgoal commonality would not compare part and whole training; it would instead compare groups whose training is either organized or not organized in accordance with the task subgoal structure. Consider a task having three subgoals (A, B, C) with four behaviors associated with the first subgoal (A1, A2, A3, A4); three, with the second (B1, B2, B3); and two, with the third (C1, C2). According to the subgoal commonality view, training should be organized in three units, each corresponding to the three subgoals. In contrast, a suboptimal organization may specify that objectives into three units consisting of three behaviors each: (A1, A2, A3), (A4, B1, B2), (B3, C1, C2). To date, no comparison of alternative part task procedures has been performed.

Evaluation. In summary, this review indicated that there are theoretical (as well as common-sense) reasons for organizing objectives on the basis of common subgoals. Furthermore, to the extent that many gunnery tasks are sequential in nature, this rule would appear to have particular relevance to gunnery. The rational and empirical methods for determining memory organization are potentially useful for determining an appropriate structure for gunnery training, although there is a lack of empirical evidence indicating that this structure does, in fact, facilitate skill acquisition.

### Commonality in Attentional Resources

In contrast to sequential tasks, the components of some tasks are performed simultaneously, that is, components must be time-shared. Partitioning the components of time-shared tasks for part training has been termed fractionation (Naylor, 1962). A number of researchers (e.g., Knerr et al., 1986; Wickens, 1989) have argued that fractionation should be designed in accordance with the attentional resources of the performer. A multiple resources conception of attention holds that the elements of such time-shared subtasks must compete for a limited pool of information processing resources. Information processing resources are hypothetical constructs in attention referring to the limited amount of "mental energy" that a performer has to

apply to a task (Wickens, 1989). The other key aspect to the theory is that there are multiple sources of this energy and that competition for this energy occurs within but not between resources. In other words, if two subtasks tap different resources, they are said to be independent and can be effectively performed together. To the extent that subtasks tap the same resources, performers must learn to time-share their attention among the subtasks. Thus, subcomponents of a time-shared task are related to the extent that they tap the same or similar processing resources.

Methods. The concept of multiple resources has evolved from empirical findings indicating the extent to which tasks can be effectively time-shared and other lines of converging evidence. Wickens (1989) suggested that global task characteristics can be used to predict the results from these studies and thus define the different resource systems. These critical task characteristics can be described in terms of three dimensions: (a) stage of processing (encoding, central processing, responding), (b) processing codes (analog/spatial vs. verbal/linguistic), and (c) processing modalities (auditory vs. visual perception, and vocal vs. manual responses). Wickens predicts that ". . . two tasks that share common levels on the dimensions will suffer greater interference than two that demand separate levels" (p. 82). This qualitative three-dimensional model of multiple resources provides, in essence, heuristic guidelines for organizing components of a time-shared task.

Mané and his colleagues (Mané, Coles, Karis, Strayer, & Donchin, 1984; Mané, Coles, Wickens, & Donchin, 1983) developed empirical procedures for determining these relationships among subtasks of complex time-shared tasks based on Sternberg's Additive Factors approach. According to their empirical approach, if the effects of two independent variables on performance are additive, the factors must be affecting independent (i.e., different) information processes. On the other hand, if the effects are interactive, they are related in their effect on a common information processing resource. Their prototypical analysis, which focused on a complex and interactive computer game (Space Fortress), identified three skill components: appraisal, motor, and perceptual-motor. Only appraisal and motor skill components were shown to interact, but only under speeded response conditions.

Based on the results from their previous analysis, Mané, Adams, and Donchin (1989) designed three drills that were intended to provide practice on each of the three components identified earlier. Subjects in the part-training group practiced these skill components individually prior to performing the whole task. After part training, subjects were transferred to the whole-task (control) condition and run to a performance criterion. Results indicated that the part-training group reached the criterion more quickly than did the control group who practiced only under whole-task training conditions. In fact, the time saved in the part-training group was more than the time required for the whole-task training. In other words, the part-training regimen resulted in greater than 100% transfer to whole-task performance. To interpret these findings, Mané et al. suggested that the superiority of part over whole training was due to the fact that part training allowed the subjects to study in isolation the action-outcome relationships of a subset of task elements. These relationships were less salient in the whole training regimen, and performance consequently suffered. In summary, the results from this research support the notion that independent skill components can effectively be trained in isolation.

The results from Mané et al. (1989) also provide partial confirmation of the multiple resource conceptions discussed above. To provide even stronger evidence for the multiple resources concept, research should be performed that factorially combines interacting and independent skills with part and whole training. The prediction is that whereas part training would produce better learning for independent skills (a replication of Mané et al.'s findings), whole training would produce superior performance for interacting skills. To further illustrate this prediction, three basic but distinct tank commander skills related to gunnery can be performed simultaneously: (a) target acquisition, (b) manipulation of commander's control handles, and (c) radio communication. The first two skills (target acquisition and control handle manipulation) both require spatial/analog coding of information rather than verbal/linguistic coding as required by the third skill (radio communication). The prescription that may be derived from this qualitative analysis of processing requirements is that, whereas radio communication may be trained apart from the other two components, target acquisition and control handle manipulation should be trained together. A possible mitigating variable is level of training. With high levels of practice, skills become automated and require a lower level of processing resources (e.g., Salmoni, 1989). It is possible, then, that high levels of part training may be effective for interacting skills if they are sufficiently automated. In summary, these predictions suggest a three-way interaction exists among training strategy (part vs. whole), relation between skills (independent vs. interacting), and level of training (low vs. high).

Evaluation. The research findings from controlled experiments provide limited support to the view that, to the extent time-shared skills tap qualitatively different resources, they can be successfully trained in isolation. This view also implies that, to the extent time-shared skills tap the same resource, they must be trained together so that the trainee learns the appropriate attentional skills. It should be cautioned that the findings are relatively new, and these methods have not been applied to "real world" jobs. Thus, the suggestions for organizing training arising from attentional considerations should be regarded as tentative, and perhaps topics for research in their own right.

Two limitations to implementing these methods are apparent. First, many gunnery skills are strictly sequential and, therefore, not relevant to the analysis of multiple resources. The most relevant aspect of the gunnery domain would appear to be the skills performed by the tank commander who must time-share his attention between procedural gunnery tasks and command/control tasks. Second, the empirical analyses performed by Mané and colleagues would probably be impractical for most gunnery applications, other than for research purposes. On the other hand, as demonstrated by the preceding example, Wicken's conceptual description of multiple resources may serve as a useful heuristic guideline to the developer of training strategies.

#### Summary of Recommendations for Structuring Training

The strategies related to structuring training were discussed in terms of relationships existing among objectives. To the extent that the relations can be objectively measured, algorithmic procedures (e.g., cluster analyses) can be used to organize the objectives. In fact, the research by Morrison (1984) indicated that these approaches are possible for defining commonality

in task subgoals. However, for the most part, the current state of the art does not support objective criteria for the relations that exist among training objectives. Therefore, the best methods remain heuristic guidelines. The resulting best methodological guidance can be summarized in terms of the following heuristic.

Any pair of objectives should be trained together given that one of these four conditions exists:

1. one objective is dependent on the other, that is, it has the other as a prerequisite);
2. one objective supports the other, that is, it transfers to the other;
3. both objectives are sequentially related and share a common task subgoal; or
4. both objectives are time-shared and share a common attentional resource.

#### Sequence Training

The structures identified by grouping cognate objectives do not yet incorporate recommendations for the order in which the grouped training units should be presented, although such sequence effects have a potential influence on training effectiveness. The optimum sequencing of training must take into account the relationships among objectives, and among the media/devices that support those objectives. Given that training has been structured into separate instructional units, there are at least two levels at which the problem of sequencing may affect training. First, the efficiency or effectiveness of training may vary as a function of the sequencing of instruction *within* training units. For example, within a unit of instruction related to target engagement there may exist sequences other than the natural order which would maximize the impact of instruction. Second, sequencing may also have important effects *between* clusters of training units. For instance, there may be better reasons for carrying out practice on precision gunnery before degraded mode gunnery. In addition, it can be argued that sequencing issues arise in connection with the use of the training *devices* to which segments of training are allocated, separately from the nature of the training content itself.

It is unlikely that the literature will provide definitive answers to many of these sequencing problems, as these have not typically formed the subject of empirical research. However, there are a number of general principles that should offer broad guidance for provisional recommendations. Branson et al. (1975) made the points that (a) sequencing effects are long-range, and unlikely to be revealed before end-of-course assessment; (b) sequencing is important to low-aptitude students; (c) sequencing is important with unfamiliar materials; and (d) sequencing is important to non-redundant materials. The ISD document provides recommendations for dealing with learning objectives with dependent relationships, supportive relationships, or independent relationships, using the logic of the subject matter as the basis for classification. In general, the majority of the

published recommendations concerning sequencing (e.g., Gagné, 1967; Merrill, 1987; Reigeluth & Curtis, 1987; Ryder, Beckchi, Redding, & Edwards, 1988) have been based on relationships within the subject matter. Since many of these relationships are hierarchical in nature, these recommendations will be reviewed under the general heading of "Hierarchy." However, there appear to be several considerations deriving from practical and experimental research, extraneous to the nature of the subject matter to be trained, that should also play a part in determining sequencing.

Some instances of such sequencing principles are already incorporated in Army training practice. Morrison (1985) reported the following recommendations for sequencing within clusters from the Training Development Handbook for the U.S. Army Armor School:

1. Job performance order. Objectives should be trained in the same order that they are performed on the job.
2. Chronological order. Objectives corresponding to events should be trained in the same order as they occur.
3. Cause and effect. Instruction on the causes of an event should precede a description of the effects of an event.
4. Critical sequence. Any critical sequence in a procedure must be trained in the order the sequence occurs.
5. Simple to complex. Simple objectives should be trained prior to complex ones.
6. Known to unknown. Familiar topics should be handled before unfamiliar ones.

It is suggested that the same recommendations should be applied to sequencing between clusters, with the additional suggestion that it may be possible to follow the order exhibited by a tactical scenario. The above recommendations suggest several other main categories for the analysis of sequencing. For the present purposes, it appears sufficient to group together the principles of job performance order, chronological order, and critical sequence as instances of "Natural Order." Following a tactical scenario may be regarded as a further instance of the same type. Army practice also sanctions a principle known as "Crawl-Walk-Run," which deserves separate consideration on its own merits. The list above contains three further principles, including cause and effect, simple to complex, and known to unknown. Cause and effect will not be considered below, since there appears to be no strong backing for this rule. In fact, in teaching medicine it is not uncommon for symptoms to be learned before the etiology of diseases. The known to unknown principle reflects the usual educational practice, and may be subsumed with the other instructional recommendations under the general heading of "Hierarchy." However, the simple to complex recommendation raises issues connected with asymmetrical transfer of training between easy and difficult tasks, and will be reviewed under the section entitled "Task Difficulty." In summary, three important categories for sequencing instruction are (a) Natural Order, (b) Crawl-Walk-Run, and (c) Task Difficulty.

In addition to the categories already mentioned, two further types of principles deserve consideration. The first of these is the principle of "Chaining", which is derived from the body of research on part-task training. The other is a principle entitled "Alternation," which in this connection refers primarily to the practice of giving varied exposure to different devices. The evidence for such a principle is mainly indirect, but logically compelling. The principles, or groups of principles, to be evaluated are summarized in Table 1. The table shows the general titles used, the area of research or practice from which these principles derives support, and the level of application of the principles (between training units; between devices; within training units). All five groups of principles are discussed in more detail in the following sections.

Table 1

Principles of Sequencing

Principle	Original Context	Level of Application
Hierarchy	Cognitive structure	B, D, W
Natural Order	Standard procedure	B, W
Crawl-Walk-Run	Army practice	B
Task Difficulty	Transfer of training	B, W
Chaining	Part-task training	B, W
Alternation	Simulator fidelity	D

Note. B = Between units; D = Between devices; and W = Within units.

Hierarchy

Various approaches to motor control and learning incorporate hierarchical principles of cognitive organization. Thus, most current theories of skill make the assumption that control is exerted through at least two levels. For example, an idea common to theories of typing, writing, speech production, and musical performance is that a higher level of control determines the nature of a given activity, while a lower level governs the execution of motor commands (Colley, 1989). The implications for training, were examined by Mackay (1982), who concluded that transfer, although relatively specific, occurs at the higher levels of organization. However, such theories appear to have no direct implications for the sequencing problem. What is clear from this hierarchical perspective is that the programming of response sequences must normally precede their execution, so that control is passed sequentially from higher to lower levels. On the other hand, it cannot be assumed that training objectives should follow the same

order. In fact, hierarchical theories usually hold that lower levels should be learned prior to higher ones.

Methods. It may appear, at first, that applying the notion of hierarchy to the principles of instruction should make an important contribution. Gagné (1967), for example, has long argued that learning takes place at a number of different levels of generality. Specifically, he proposed that a sequence is imposed by the requirement that acquisition at each level is dependent on prior mastery of the underlying (prerequisite) level. Thus, a high-level skill such as problem-solving assumes a mastery of rule using, classifying, multiple discrimination, verbal and motor chaining, and specific responding (in that order) with mastery at each level imposing different preconditions. Without accepting this analysis in full, there is no doubt that many subject matters dictate their own logical progression. However, it is by no means clear that tank gunnery requires all of these levels. In any case, the most natural application would be within training units, so that the analysis provides little guidance for sequencing between units.

Many authors concerned with structuring subject matter have employed versions of schema theory in conjunction with hierarchical concepts. Morris and Rouse (1985) considered and evaluated several training methods for troubleshooting, coming to the conclusion that the most efficient technique is one in which trainees are specifically taught to make lower-level applications of general theoretical principles. As Ryder et al. (1988) pointed out, this method of teaching prototypical concepts first, followed by variations, structures new information in a way that can most readily be related to existing schemata. The general sequencing model described by Reigeluth and Curtis (1987) depends on providing opportunities for integrating applications and theory by using forms of progressive elaboration. This approach is where training begins with the shortest path through the network of possible procedures; procedural branches (elaborations) are systematically added until the entire network is learned. However, the method of choice may depend on the volume of material to be covered. Merrill (1987) favored what he terms the "hierarchical part-whole" relationship among component parts of a task to be taught, but considers the exception when a task can be taught in one instructional session. In these circumstances, a major step in the hierarchy and its substeps may be taught at the same time.

In any case, the notion of hierarchy as applied directly to memory organization seems potentially capable of producing more specific recommendations. Morrison (1984) demonstrated the application of proximity analysis to clustering in the memory scores of armor crewmen for the procedural elements of a machine gun task, which required performance in a fixed order, and in a tank radio task, which did not. In both cases, the combination of clustering techniques with rational analyses of goals and subgoals gave rise to interpretable tree structures. In this case, however, the derived structure for the gunnery task shows levels of control such as (a) "clearing the M240" requires "unload" and "return" operations, (b) "unload" in turn requires "charge bolt," "open receiver," and "remove ammo," and finally (c) "open receiver" requires "place in SAFE" and "open cover." These phases of operation do not necessarily correspond to successive training requisites. In fact, Hoffman et al. (1983) compared top-down and bottom-up training strategies using similar memory organization analyses and failed to find differences between the two approaches to sequencing.



Hoffman and Morrison (1988) made rational, hierarchical analyses directly targeted at identifying the prerequisite skills and the instructional sequence for tank gunnery training. The analysis suggested, as indicated above, that gunnery consists of a large number of relatively simple subtasks. Hence, the structure of the gunnery domain may be described as "wide, but not very deep." If it is the case that gunnery consists of many disparate activities, each of which relies rather little on prerequisite skills and knowledge, the contribution of a hierarchical analysis to sequencing problems will be relatively slight. Nevertheless, the associated principle of progressive elaboration, which suggests that the learning of a core activity should precede the learning of more complex versions of the task, should be borne in mind.

Evaluation. Although hierarchical principles do not provide a complete or automatic solution to sequencing problems, it is possible to identify some specific applications of the notion that certain instances of learning should precede others. Between training units, for example, there may be a logical case for learning tank commander duties before attempting to learn the coordination between tank commander and gunner. Again, although there is some doubt as to how the hierarchy principle should be applied, it may be possible to argue that some degraded mode techniques represent more primary skills, and that these should be taught before practice on some non-degraded mode techniques. However, although some degraded mode techniques may be more primary from a technical standpoint, the skills required are probably more demanding. With regard to sequencing between devices, it must be determined which of the devices trains the more basic skills.

### Natural Order

The recommendation that training should follow the natural order of the task or subject matter to be trained is an obvious and implicit rule for instructional sequencing. Thus, it may be considered the "default" sequence for training.

Methods. As already indicated (Morrison, 1985), the natural order principle may be applied at several levels. With respect to specific jobs, training objectives should be sequenced in the order that they are normally performed. In a number of cases, no practical alternative exists because the job order constrains the logical sequence of training. Thus, when preparing a defensive position, an instructional objective entitled "Select a Firing Position" should be trained before the objective entitled "Prepare a Sketch Range Card," because the tank must first be in a firing position before the crew can prepare a sketch range card. The alternative approach of preparing or simulating an artificial firing position in order to allow range card practice can only be justified in special circumstances.

The more general guideline concerns the chronological order of events, suggesting that objectives should be trained in the same order as the corresponding events normally occur. Thus, the activity "Maintain Position in Platoon Formation" takes place after the initiation of "Conduct Tactical Road March," and the corresponding training objectives should be sequenced in the same order. The initiation of the road march activity presents the cues needed to initiate the position maintenance activity, so that the first activity naturally leads into the other. Again, certain activities are

physical precursors of other activities, or else constitute strongly coercive preconditions. If the required activity is to charge a machine gun, the safety must be off before pulling the bolt to the rear. Hence, it is clear that training should be administered with reference to putting the safety in the "Fire" position before training the charging procedure. In this form, the guiding principle is that of critical sequence.

Evaluation. The recommendations of this section are relatively clear, although it is possible to contemplate some exceptions. For example, the principle of "backward chaining" (see below) would override the requirements of natural order if shown applicable to the objectives otherwise governed by the principle of natural order. However, given the relative lack of evidence favoring backward chaining as against other directions of part-task sequencing, there is currently no reason to avoid following job performance order, chronological order, and critical sequence order.

### Crawl-Walk-Run

A traditional Army approach recommends that trainees should first learn to crawl, then to walk, and finally to run. Although this principle seems to encourage gradually increasing demands on the trainee, its exact interpretation may take several forms, some of which are described below.

Methods. The crawl-walk-run method appears at first sight to reflect a concern for training accuracy while speed is gradually incremented. Accuracy first and speed later typifies the acquisition of many skills, although it is sometimes objected that speed changes the form of response so that accuracy later should be preferred. The older work on speed versus accuracy training indicates that the issue is relatively unimportant (Holding, 1965), because there are few tasks whose manner of performance is radically altered when practiced at different speeds. In fact Poffenberger's Law, sometimes invoked in industrial psychology, states that any task initially learned to an accuracy criterion can later be performed at successively greater speeds. There are a number of exceptions to this generalization due to special considerations such as response timing, pacing, or sharing. However, none of these exceptions has any established relevance to sequencing.

A different interpretation of the principle is reported by Drucker and Morrison (1987), who described the crawl stage as an orientation phase, perhaps with verbal instruction and visual demonstration; the walk phase as consisting of task practice, but in isolation from other activities; and the run phase as integrated performance in realistic contexts. This interpretation is somewhat reminiscent of Fitts' (1964) sequence for skill acquisition, which comprises cognitive, associative, and automatic phases. However, the crawl-walk-run formula also seems to imply a progression from easy to difficult conditions of practice (see below), together with the use of increasingly realistic contexts. The principle, as expanded by Drucker and Morrison, further implies that training objectives should be learned repetitively. This should result in a degree of overlearning, which in turn should provide some resistance to stress effects. In addition, the repetition should make it possible to expose the learner to a variety of different practice materials, a factor which Wolfe (1951) already recognized as contributing to successful training. Hence, the principle may also be related to the recommendation for alternation discussed below.

Evaluation. None of the above interpretations seems in any way objectionable. However, the principle is apparently too complex to offer clear guidance with regard to sequencing, although it does provide several useful pointers. Among these, note that the gradual increase in speed, the implied repetition, and the increase in realism are all most naturally applied between rather than within training units. The principle overlaps with others discussed below, including the training recommendations based on task difficulty and alternation of practice.

### Task Difficulty

As indicated above, the crawl-walk-run approach may be interpreted as implying an easy-to-difficult direction for training, if not an explicit progression from slow to fast. In any case, the easy-to-difficult sequence deserves consideration in its own right.

Methods. The normal educational sequence is to proceed gradually from easier to more difficult aspects or versions of the task to be learned, just as from the known to the unknown. This form of progression is basically compatible with the principles of programmed learning, which in turn derive support from the behavior shaping literature. As Holland (1960) reiterated, the programmed learner should be led by gradual stages from what he knows at the outset toward the goal of the training. Each new step brings a small increase in complexity, so that the learner can readily master the new material and therefore achieve a high rate of success.

A potential complication is that the progression of learning from one trial, exercise, or session to another may be viewed as a form of successive transfer of training. Because there are some examples in the literature where better transfer of training occurs in the difficult-to-easy direction, it is sometimes assumed that this may be the superior order for practice in a training program. In fact, there are anecdotal accounts of medical students learning to perform surgical operations using the left hand (the more difficult version), on the assumption that there would later be automatic transfer to the (easier) right. However, it is easier to find examples in the easy-to-difficult direction.

In general, it appears that perceptual tasks give rise to better easy-to-difficult transfer, as do changes in target speed and amplitude in tracking studies (Holding, 1987). The opposite result (i.e., better difficult-to-easy transfer) tends to occur with other forms of task complexity, with changes in control characteristics, and with reversals of display-control relationships. However, small changes in task variables can produce transfer in both directions within the same experimental paradigm. It appears that the results can be explained in terms of the tradeoff between two opposing tendencies: One tendency is the principle of inclusion, which results in the trainee learning more (i.e., more habits, skills) on the difficult version of a task; the other is the principle of performance standards, which leads to the trainee learning better response habits on the easier version.

Inclusion takes place, for example, when a trainee learns to track a difficult target course whose bandwidth literally includes the frequencies used in the easier target course. The operation of the inclusion principle was been verified in a complex tracking task by Williges and Baron (1973),

although there appear to be few instances in which such a principle is applicable to armor training. On the other hand, the operation of the performance standards principle appears to explain the recent results of Lintern, Roscoe, and Sivier (1989). These researchers found better transfer to a flight task with crosswind by groups learning without crosswind (easy) than by those learning with a crosswind (difficult), despite the fact that the criterion task was identical to the difficult version. In any case, there may be a substantial difference in the time required for original learning in the two directions of transfer regardless of the optimal direction for transfer itself.

It is important to note that the optimum direction of transfer may not be the best direction for training. That is, one cannot equate transfer percentage with training time. Even with better transfer in the difficult-to-easy direction, the combined training times for the two versions may exceed the training time in the reverse direction. Table 2 gives a hypothetical illustration of this effect. Learning to play the organ to some criterion may take 200 hours, dropping to 140 after first learning the piano. There is thus a saving of 60 hours, out of 200, giving a transfer value of 30 percent. In the other direction, the piano learning time drops from 100 to 60 after the organ, for a transfer value of 40 percent. Organ-to-piano, the difficult-to-easy combination, therefore shows superior transfer. Nevertheless, the most efficient training sequence consists of progressing from piano to organ, since the overall training time for both tasks totals 240 hours, instead of 260 hours. The issue of total time is an important factor in allocating training time, which is discussed in more detail in the section concerning that particular problem.

Table 2

Asymmetric Transfer versus Training Sequence

Sequence	(Piano -) Organ		(Organ -) Piano	
	Hours	(Percent)	Hours	(Percent)
As Control (1st) Task	200		100	
As Transfer (2nd) Task	140		60	
Savings	60		40	
Transfer Value		(30%)		(40%)
Both Tasks	240		260	

Evaluation. Obtaining better transfer from first learning a difficult task is clearly of no benefit if the difficult task itself requires an extended learning period. The majority of applied training studies, like those in education, seem to concur in finding the easy-to-difficult direction

preferable. The recommendation is to move from easy to difficult provided that the potential for direct inclusion is absent.

### Chaining

Backward and forward chaining are techniques of part-task training for skilled tasks that (a) are amenable to segmentation, and (b) exhibit sequential properties. When appropriate, the chaining method has implications for both the order and the amount of practice on task segments. In a task divided into 3 segments (A, B, C), backward chaining would refer to practicing first C, then BC, then ABC; forward chaining would refer to practicing first A, then AB, then ABC. Note that backward chaining thus entails more practice on segment C, and forward chaining requires more practice on segment A. The advantage of chaining is that practicing overlapping segments should help to integrate the sequence, thereby overcoming the problem that extra trials may be needed for reintegration after part practice.

Method. The chaining concept has no application in a task, such as dart-throwing, for which segmentation is impracticable. In such cases, it may be that other part-task training methods (e.g., task fragmentation or simplification) are more viable alternatives for part-task decomposition (Wightman & Lintern, 1985). However, these methods have no relevance to the sequencing problem. It also appears that chaining methods are irrelevant to tasks in which the order of practice of the segments is unimportant, such as the identification of a set of targets. A case in point was reported by Singer (1968), who examined the acquisition of skill at volleyball. Part-task practice on the component subskills (serving, digging, setting and spiking) was superior to whole-task training, but the order in which these subskills were learned had no effect on the final outcome. Mané et al. (1989) have also obtained superior performance for part-task training compared to whole-task training without specific chaining. On the other hand, experiments on aircraft simulator training on tasks that are more clearly sequential in nature (e.g., Bailey et al., 1980) have obtained apparent performance advantages for part-task training with backward chaining.

The task components in volleyball do appear to preserve a modicum of natural order, but it is evident that a stronger ordering must be required if any chaining effect is to be observed. Hence, it may be argued that the chaining principle is more likely to find application within the instructional units for tank gunnery, where the ordering is more coercive, than between these units. Within a unit on target engagement, for example, there appears to be a strong ordering of components such as rotating the turret, aligning the sights, squeezing the trigger, and then observing the outcome. Between units, on the other hand, an ordering may be imposed by the need for target identification to precede marksmanship, but it seems dubious whether this degree of ordering satisfies the necessary conditions for chaining.

For the cases where chaining is appropriate, it should be noted that the apparent advantages of the backward form of chaining may be unreliable. In the earlier work on flight simulators reviewed by Wightman and Lintern (1985), the effects of segment order were confounded with the effects of segment difficulty. Specifically, the problem arises because the final segments of such tasks as aircraft landing were practiced first, and practiced most often, when backward chaining was in place. These segments were also the most

difficult, and were the segments that resulted in the greatest amount of knowledge of results. These findings should be contrasted with the data reported by Ash and Holding (in press) where difficulty and segment order were systematically counterbalanced. The latter work, contained in a dissertation by Ash (1987), used a keyboard task of musical performance. The use of music as the medium is less relevant than the fact that the task involved a form of keyboard encoding and translation. In fact, the musical stimuli conferred a degree of natural ordering, and made it possible to counterbalance the ordering of difficult and easy segments of the task. Knowledge of results was held to a minimum throughout training. Backward and forward chaining were compared with whole training on (a) whole-task criterion trials immediately following the training procedure, and (b) whole-task retention trials one week later. Both forms of part-task training gave results superior to the whole-task training, but forward chaining led to better learning than did backward chaining.

Evaluation. It is possible to argue that the above results arose as a consequence of the special characteristics of the musical performance task, which is a discrete-response task as well as sequential. Further work is now being conducted to replicate Ash and Holding (in press) using a continuous task instead. However, it appears more probable that the earlier results favoring the backward direction were due simply to the omission of a forward chaining condition. Because both backward and forward chaining were superior to whole-task training, there is implicit confirmation of the idea that overlapping practice is beneficial. There have been no direct comparisons of chaining against simple partitioning methods, and it is again clear that further experimentation is required. In the absence of contrary evidence, it can be presumed that the overlapping practice contained in chaining procedures has beneficial effects. With respect to the direction of chaining, the preliminary conclusion must be that forward chaining, which has the advantage of preserving the natural order of the task, is the superior alternative. This conclusion may require modification in practical cases where segment difficulty and knowledge of results cannot be made independent of task order.

### Alternation

As shown in Table 1, sequencing by alternation is most naturally applied to training devices, rather than to objectives. The principle of alternation between devices has no direct empirical backing, but represents a logical response to the problems of incomplete device fidelity. Alternating between different devices also provides the benefit of varied practice, and should assist trainees in developing a mental model of the overall armor system. Possible interactions between the requirements of alternation and such techniques as part-whole training have not been investigated.

Method. It has often been confirmed (most recently by Lintern, Sheppard, Parker, Yates, & Nolan, 1989) that strict physical fidelity is of less importance than psychological, or functional, fidelity. Nevertheless, even small departures from physical fidelity will make for some difficulties in transferring from training equipment to the real task, particularly as the duration of training increases and as learning consequently becomes more specific. Except when fidelity is perfect, device-specific responses will be found inappropriate to the real task. It seems apparent that alternating between different devices, whose departures from fidelity may take

complementary forms, should permit the trainee to build a more adequate cognitive model of the target skill, thus producing an effective increase in psychological fidelity. Furthermore, rotating between devices increases the variety of practice during training. The conclusion that device alternation should be recommended therefore receives additional support from the consideration that using a variety of practice materials is known to improve learning, as mentioned earlier. The variety principle is further sanctioned by Schmidt's (e.g., 1975) schema theory, and gives rise to more generalizable transfer effects.

A further step in alternation should be to include the real-world equipment, in this case the M1 tank, in the rotation between devices. This procedure should not only increase the variety of training practice, but should have two further desirable consequences. First, the real equipment will provide a stable reference for the correction of misapprehensions based on minor deficiencies of the simulator devices, which can then be discounted. Second, early experience with the real equipment helps to define the goal of the training exercise, ensuring that training takes place in a functional context. It is a tenet of Bandura's (1986) theory of observational learning, for example, that little progress can be made until the trainee constructs a cognitive model of the target activity. Again, Gray and Orasanu (1987) emphasize the part played by mental models in training for cognitive skills. It seems essential that trainees should fully "understand" the system in which they are to operate, building a cognitive model which can be supplemented or modified as further learning takes place.

Evaluation. The above conclusions appear relevant to gunnery training objectives, suggesting that exposure to varied devices, including the actual tank, should change the trainees' semantic interpretation of training exercises. Varied practice should lay the foundation for more flexible performance in later applications, with a consequent increase in training effectiveness. Including early exposure to the real task should help to overcome deficiencies in simulator fidelity, and should assist trainees in building an adequate mental model of the target system. However, this aspect of sequencing has been insufficiently researched, and there is a clear need for applied experimentation on this issue.

#### Summary of Recommendations for Sequencing Training

Reviewing the available principles for the sequencing of training units has produced a set of conclusions varying widely in degree of empirical support and in applicability to the problems of armor training. The preceding analyses have screened out several potential sequencing principles, but there remains a core of rules which appear to be provisionally supported. It should be noted that no direct evidence supports the notion that the sequencing of instructional units is of greater importance than are many other training variables. Nevertheless, the use of these principles should play a part in optimizing the conditions that determine training effectiveness. Table 3 provides a brief summary of the best supported recommendations.

The analysis has thus given rise to 6 groups of sequencing principles, distinguishable into 15 separate rules. As Vineberg and Joyner (1980) note, there are many instances in which such principles will result in conflicting recommendations, and reconciling the recommendations stemming from such an

array of variables must inevitably involve a degree of compromise. However, it will become apparent that there are few serious conflicts between the stated principles in the context of armor training. The applications section of the present report considers illustrative uses of the principles, showing considerable similarities between the resulting recommendations for the order in which practice should be conducted.

Table 3

Summary of Sequencing Rules

---

1. Hierarchy
    - 1.1 Teach ends before means.
    - 1.2 Follow the logic of the subject matter.
    - 1.3 Use progressive elaboration.
  2. Natural order
    - 2.1 Follow job performance.
    - 2.2 Follow chronological order.
    - 2.3 Observe critical sequence.
  3. Crawl-walk-run
    - 3.1 Move from slow to fast practice.
    - 3.2 Move from orientation, through practice, to real task.
    - 3.3 Repeat practice in different modes (cf. #6).
  4. Task difficulty
    - 4.1 Transfer order is not training order.
    - 4.2 In general, progress from easy to difficult.
  5. Chaining
    - 5.1 Use overlapping forms of part practice.
    - 5.2 Follow the natural sequence of the task (cf. #2).
  6. Alternation
    - 6.1 Vary practice between training devices.
    - 6.2 Provide real equipment experience early in training.
- 

Select Media/Devices

The third problem addressed by training strategies concerns the selection of media or devices for training. For previous strategies, we decomposed the overall problem into multiple subproblems and discussed approaches to each of the subproblems. In this regard, Kribs, Simpson, and Mark (1983) provided a reasonable decomposition of the media selection problem into three subproblems: (a) determine the requirements of the objectives to be trained, (b) determine the capabilities of training media, and (c) specify the best match of requirements and capabilities. The unique aspect of this strategy is that media selection models have been designed to address all three aspects of this problem rather than any one aspect. Hence, the



following models necessarily overlap in function. The first two sections address some previous models from the literature, and the third proposes a model based on utility theory that has some distinct advantages over the previous models.

### Models Based on Analysis of Learning Activities

One group of older media selection models can all be traced to the instructional theories of Robert Gagné and his colleagues. Gagné has consistently maintained (e.g., Gagné, 1984) that learning activities can be linked to certain types of learning outcomes. For instance, specific learning prescriptions (e.g., telling students what they are expected to know) may work for some outcomes (e.g., procedural knowledge), but not for others (e.g., attitudes). This assumption is central to his media selection procedures as well as other procedures within his model for training development.

Method. The prototypical example from this group is the model developed by Braby, Henry, Parrish, and Swope (1975) for the Training Effectiveness Cost Effectiveness (TECEP) methodology.<sup>2</sup> They started by developing an 11-category taxonomy of learning outcomes similar to that espoused by Gagné. Each outcome was then associated with a set of prescribed learning activities. Some learning activities are common to all types of tasks, for example, inform student of the objective, provide appropriate practice experiences, and provide performance feedback. Other activities are more appropriate to certain types of learning outcomes. Examples of specific prescriptions include (a) acquisition of motor skills is best suited to hands-on practice; (b) visual discrimination requires presentation of critical stimuli; and (c) information retention is benefitted by active restatement of the information in different contexts. Included in the prescription for each category of learning outcome is the specification of appropriate training media and criteria for choosing among them. The media selection guidance is provided in the form of a two-way chart indicating whether or not media meet each of the criteria. The user indicates which of the criteria must be met for his/her particular application. The user then selects the media alternative(s) that most closely matches his/her set of criteria.

Evaluation. The strength of the device selection approach typified by TECEP is that it selects devices according to the activities required to learn the tasks. On the other hand, some users have criticized the procedures for classifying learning outcomes and for specifying learning activities as not well developed (Vineberg & Joyner, 1980). Other users have suggested that these sorts of guidelines are primarily aimed at the training developer who is conversant with instructional technology terms. Those who are not conversant with this technology are likely to misunderstand terms that are essential to the application of this model. Another criticism of the TECEP approach is that the list of media alternatives is overly broad with a bias toward cognitive (i.e., academic) type media. Furthermore, there are typically no provisions for adding to or modifying the list. This problem is particularly acute for gunnery training, which is supported by a variety of special-purpose

---

<sup>2</sup>This model was incorporated in the Interservice Procedures for Instructional Systems Development (Branson et al., 1975). Therefore, some researchers identify this as the ISD procedure for selecting media.

training devices and technologies. Finally, the output of these models is limited to a dichotomous indication of whether or not a medium is appropriate for training. In many cases, it would be useful for the training developer to have more scalar information about the devices, for example, the relative ranking of devices with respect to training a particular objective.

### The Automated Instructional Media Selection (AIMS) Model

Kribs et al. (1983) reviewed extant device selection models and provided criticisms similar to those stated above. They also argued that the process of matching devices to training requirements is needlessly labor intensive and would be greatly aided by computer implementation.

Methods. Their approach to device selection, the Automated Instructional Media Selection (AIMS) model, was specifically developed in reaction to these deficiencies of earlier models. In general, AIMS takes a less theoretical and (therefore) more flexible approach to device selection. In the device selection approach typified by TECEP, both device and instructional attributes are fixed. In contrast, AIMS users generate both of these sources of data to apply to their particular needs. The list of devices may only include those that are available to the user or may include all applicable devices, available or not. Instructional attributes may include hardware/software capabilities (e.g., existence of color visual displays) or attributes more psychological in nature (e.g., the immediacy of feedback).

The instructional attributes provide a basis for describing the training requirements and device capabilities. The AIMS procedure starts with the user generating a list of media/devices and a list of instructional attributes. He then rates the degree to which each device is capable of delivering each characteristic on a scale of 0 to 5. A rating of 0 indicates that the device has essentially no capability for delivering the characteristic in question, whereas a rating of 5 indicates the device is "very capable" of delivering the characteristic. Next, the user indicates, for each task, whether or not each characteristic is required. The AIMS software then calculates the average rating and rank ordering of each medium over all attributes ("general" rating) and the average rating and rank ordering for only those attributes that pertain to specific tasks ("specific" ratings).

Evaluation. One of the most favorable aspects of AIMS is its inherent flexibility and adaptability. Furthermore, because of its computer implementation, the model is able to perform multiple runs of the data under "what if" conditions. On the negative side, the ratings data are not handled in a mathematically sophisticated manner. This leads to two specific problems of interpretation. First, the averaging procedure assumes that the instructional attributes are equally weighted over all objectives as well as for individual objectives. Consider attributes of fidelity that could be related to gunnery such as the capabilities to simulate movement and to simulate firing. These two attributes should be differentially weighted for tasks such as "Conduct a Tactical Formation" versus "Execute a Platoon Fire Command." Second, AIMS provides not one, but multiple ratings for each medium or device. As in so many instructional development procedures, the final decision is dependent on "expert judgment." To come to a less equivocal selection, the process must somehow aggregate ratings to come to a final decision. To aggregate responses (using something more than averages)

requires some theoretical notions of the mathematics of scaling and the psychology of decision making.

### A Model Based on Multiattribute Utility Measurement Technology

An alternative to the TECEP and AIMS models of media selection is one based on multiattribute utility technology (MAUT). This MAUT-based model specifically addresses the negative aspect of AIMS discussed above. That is, MAUT provides methods for making decisions about objects (e.g., training devices) having value on a number of different dimensions or attributes. The MAUT-based media selection model is particularly interesting in that it has both heuristic and algorithmic components. The initial structuring of the decision making problem is usually heuristic in nature. In that regard, Edwards (1987) admitted that "... structuring is an art form, subject to few rules and little prescription" (p. 1066). At a minimum, this heuristic process should produce two essential products: (a) a list of options and (b) the value structure that is descriptive of the consequences of each option. Fortunately, the problem of media selection considerably constrains the problem structure in two ways. First, the options are the candidate devices themselves. Second, the value structure consists of attributes that would theoretically influence the user's choice of devices. Devising an appropriate value structure is clearly more difficult than determining relevant devices.

The algorithmic component of the method includes the mathematical and probabilistic techniques related to decision making. These techniques are algorithmic in that they ensure that a unique solution (decision) will be reached once the decision maker has sufficiently structured the problem. Furthermore, these mathematical methods are transparent to the user and relatively easy to implement. More sophisticated models of MAUT can be used to address the media selection process, but Edwards (1987) argued that more elaborate models are often not necessary to make relatively simple decisions. He referred to his recommended procedure as the Simple Multiattribute Rating Technique (SMART). According to the SMART model, the overall weighted utility ( $U$ ) of object  $i$  can be calculated as

$$U_i = \sum (w_j)(u_{ij}) \quad (1)$$

where  $w_j$  = normalized importance weight of dimension  $j$  (i.e.,  $\sum w_j = 1.0$ ),  
and  $u_{ij}$  = utility of object  $i$  on dimension  $j$

Methods. As implied in the previous discussion, the most difficult aspect of a MAUT analysis is the establishment of the value structure. The most direct definition of the value of training devices would be in terms of the training effectiveness related to each training device. As argued in the subsequent section (Allocate Training Time), such performance data are very difficult to achieve. The more realistic alternative is to rely on expert opinion. The following paragraphs present two possible approaches to this problem.

One solution to the value structure problem is to define subjective value (i.e., utility) in terms of the tasks that can be trained on a device. For instance, Metzko (1987) used a MAUT-based technique to evaluate the utility of five different armor gunnery training devices for use in the Reserve Component: (a) the Tank Gunnery and Missile Tracking System (TGMTS),

(b) the Mobile Conduct-of-Fire Trainer (M-COFT), (c) the Videodisc Gunnery Simulator (VIGS), (d) the Tank Weapons Gunnery Simulation System (TWGSS), and (e) Guardfist 1 (GF1). Metzko defined the utility of device  $i$  on task  $j$  as a simple binary rating (yes/no) indicating whether or not the task could be trained on devices. The tasks, in turn, were rated on two dimensions of importance: (a) combat criticality, and (b) need for simulation. These data were used to calculate the overall utility of each device. The utility values were then combined with simulator cost data to calculate the cost-per-task-trained for each of the five devices. These cost-utility analyses were submitted to the U.S. Army Armor School as preliminary evaluative data for decision makers.

Metzko's research indicates that MAUT can be used to make practical decisions about gunnery training devices. However, there are problems related to defining utility in terms of to-be-trained tasks. The first problem is the proliferation of tasks that relate to gunnery. The number of tasks can make the analysis tedious, but certainly not impossible. The second and more fundamental problem relates to answering the question: Can task  $j$  be trained on device  $i$ ? Hoffman and Morrison (1988) noted in their rational analysis of gunnery devices that answering this question required more than a simple yes or no. For instance, their analysis indicated that, for many tasks, devices sometimes simulated only parts of actions, or that some device stimuli and responses varied greatly in their similarity to the actual equipment. In other words, their analysis indicated that "tasks" are complex concepts and, as such, are not well suited to serve as dimensions upon which devices should be evaluated. An alternative approach is to rate the devices on attributes that should have an effect on learning. Examples of device attributes include the four dimensions of fidelity features identified by Morrison et al. (1990): (a) interior or tank-appended components, (b) exterior visual scene, (c) movement, and (d) system failures. Alternatively (or perhaps additionally), other device attributes could be considered as dimensions of value, such as the instructional features or performance measurement features of devices. In order to use these attributes in a MAUT analysis, each attribute must be rated in importance with respect to particular training applications or objectives. Thus, the utility of a particular device would vary as a function of those applications.

Evaluation. The principal advantage of the MAUT-based model over AIMS is that it is based on a theoretical model of decision making with explicit mathematical assumptions that allow the decision maker to integrate the data in a meaningful manner. In addition to this increased mathematical sophistication, the MAUT-based model also retains some of the advantages inherent in the AIMS model. First, it shares with AIMS the advantage of letting the user specify the objectives to be trained and the device evaluation attributes. Second, MAUT is easily computer programmed using spreadsheet software allowing iterative runs of the data under "what if" conditions. The obvious next step in development of this method is to try it on some representative training problem.

#### Summary of Recommendations for Selecting Devices

The recommended method for selecting devices is the MAUT-based method described above and illustrated in more detail in the following section on applications. It is important to note the difference between previous

recommendations (i.e., those concerning sequencing and structuring training) and the present recommendations. The previous recommendations were stated as general guidelines, that is, heuristics. Assuming the training developer were reasonably familiar with the training objectives, he/she could use the guidelines to arrive at appropriate strategies with little or no additional input or data. In contrast, the recommended method for selecting devices for training (the MAUT-based model) is based on "external" sources of data, that is, information from sources other than the developer's knowledge of the subject matter and training practices. To the extent that these data can be obtained or derived from objective (i.e., performance) sources, the analyst can have confidence in the results. However, it is more likely that the data for this analysis can only be obtained from ratings of devices and training objectives provided by subject matter experts. The analyst must therefore be mindful of problems related to expert opinion, and take steps to ensure the reliability and validity of these data.

### Allocate Training Time

The strategies related to the fourth problem (allocating training time) are based on mathematical algorithms for measuring transfer and cost effectiveness. These methods are detailed in the first two of the four sections presented below. Like the methods related to previously described functions (selecting devices/media), the allocation of training time requires external sources of data, specifically transfer performance data and detailed cost information. Collection of these external data creates special problems that impede the execution of these methods. Therefore, data collection issues are discussed separately in the final two sections. Thus, the four sections do not present alternative approaches to allocating training time; rather, they examine different aspects of the same approach.

### Measurement of Transfer Effectiveness

The cost effectiveness measures discussed in the next section are based on fundamental notions of transfer effectiveness. To simplify the exposition, the following paragraphs present transfer effectiveness methods without consideration of costs.

Methods. Transfer of training measures are usually derived from performance data collected from a transfer experiment. The prototypical transfer design compares the performance of two groups of subjects: an experimental group who receive training on a device and a control group who do not receive training on the device. Both groups are then tested in a second medium. The second medium may be the actual equipment itself or another (presumably higher fidelity) training device. Superior performance of the experimental group over the control group on the second medium is taken as evidence of transfer of training from the first to the second medium. Roscoe and his colleagues (Roscoe, 1971; Roscoe & Williges, 1980) have convincingly criticized the traditional method of measuring transfer for ignoring the effects of practice. They cited evidence that the amount of transfer is a monotonically increasing, negatively accelerated function of the amount of practice on the training task. In other words, increasing practice on the training task leads to decreasing increments of criterion performance. Thus, transfer effectiveness is not a single value but a function relating amount of transfer to practice on the training task.

Roscoe (Roscoe, 1971; Roscoe & Williges, 1980) discussed several different quantitative methods for measuring transfer, arguing in favor of the cumulative transfer effectiveness ratio (CTER). The CTER may be conceptually defined as the training time saved on the actual equipment due to training on a device relative to the time spent on the device itself. The function relating CTER values to different values for the time on the device (the cumulative transfer effectiveness function, CTEF) is defined as follows:

$$\text{CTEF} = (Y_0 - Y_x)/X \quad (2)$$

where  $Y_0$  = time or trials required for the control group to reach some criterion of performance,

$Y_x$  = time or trials for the experimental group to reach the same criterion of performance after  $X$  hours of device training, and

$X$  = time or trials that the experimental group was pretrained on the to-be-evaluated training device.

Roscoe (1971) showed, for various experimental tasks, that the CTEF was a decreasing function of time on the device, approaching zero for large values of  $X$ . To illustrate the calculation of CTER, however, Roscoe used hypothetical data that were intended to represent the transfer effects of a flight simulator on actual performance in a commercial aviation aircraft. His data showed decreasing values of CTER for increasing hours on the simulator, indicating that the transfer effectiveness of the simulator declines as amount of practice increases. When the function decreases to a value of 1.0, the ratio indicates that the training time savings earned by training on the device ( $Y_0 - Y_x$ ) is exactly equal to time on the device. If total training time were the only factor in allocating training time, the training device would have no further benefit beyond this point. That is, more time would be needed on the device than on the real equipment for the same effect on learning.

Holding (1977) proposed a simpler and more useful formulation for measuring transfer effectiveness. His index is the total number of hours or trials associated with the training medium and the transfer device required to reach some performance criterion (or  $X + Y_x$  in Roscoe's terms). This index is then plotted as a function of units of practice on  $X$ . If the training device is effective in reducing the total amount of training, this function will decrease to a point and then increase as  $X$  increases. The training device is assumed no longer effective (in a transfer sense) when total training time ( $X + Y_x$ ) exceeds the training time associated with the transfer device alone (i.e.,  $Y_0$ ). Figure 1 compares Holding's transfer index with the CTER for the hypothetical data generated by Roscoe (1971). For purposes of this comparison, the  $X + Y_x$  measure is expressed as a proportion of the total training time at  $X = 0$ , or  $Y_0$ . Thus, the total time function starts at 1.0, decreases below that point, then increases again. The point at which the device is no longer effective is where the function again exceeds 1.0. The figure illustrates that both the CTER and Holding's index indicate that, for the hypothetical data, this point occurs at about five hours of simulator training.

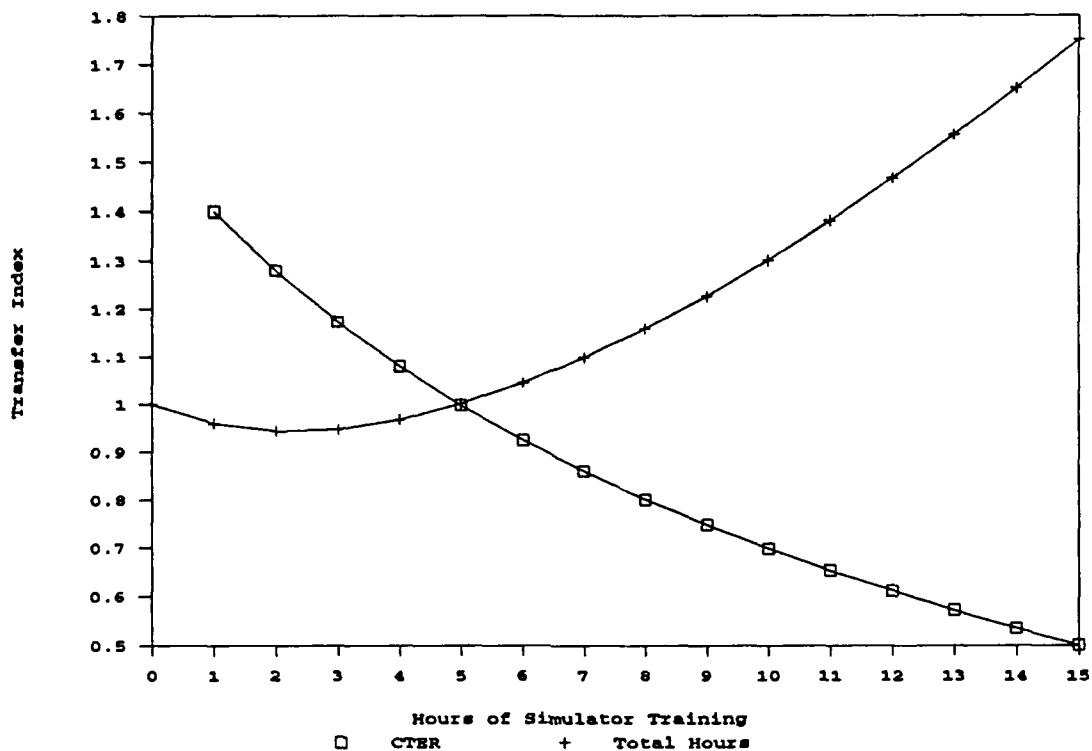


Figure 1. Comparison of transfer indexes derived by Roscoe (CTER) and Holding (total hours). (Hypothetical data from Roscoe, 1971.)

Implicit in both Roscoe's and Holding's methods is the strategy to continue training on the device to the point at which the device no longer saves training time. As clearly suggested by Holding's function, however, there is another strategy that might be to used allocate training on the device and the equipment. That is, to allocate the amount of training on the device such that total training time is minimized. This would be an appropriate strategy for allocating training given constraints on training time. As can be seen in Figure 1, that point occurs between two and three hours of training on the device. This minimization strategy is discussed in more detail below in the context of training costs.

**Evaluation.** The methods for measuring transfer effectiveness are relatively well developed mathematical algorithms and appear unambiguous in their application to gunnery training. One problem, however, is that the methods assume that for each objective there exists a single performance criterion to which crews should be trained. As discussed in the context of standard setting (Hoffman, Fotouhi, Meade, & Blacksten, 1990), performance is not well described by a single, immutable criterion of performance. The implications of this problem for the present methods are (a) that transfer

performance may be measured in units other than trials (or time) to criterion, and (b) there may be multiple indexes of performance.

### Measurement of Cost Effectiveness

If the cost rates (cost per unit time) for training with a training device and with the actual equipment media were equal, one possible strategy to allocating training is to allow training on the device to continue until the device no longer saves training time, that is, to the point where total training time on the device and actual equipment exceeds time to train using the actual equipment alone. Using this strategy and the previous data in Figure 1 as an example, one would allocate five hours of training on the device before transferring to actual equipment. However, most training devices (e.g., computer-based simulators) are designed to be much cheaper than actual equipment in providing practice on to-be-learned tasks. Thus, training devices can continue to be cost effective beyond this point. The following paragraphs discuss methods for allocating training time in light of cost effectiveness considerations.

Methods. If cost rates were constant (i.e., training costs were a simple linear function of training time), the point where device training is no longer cost-effective can be directly calculated from the transfer effectiveness functions discussed above. Using the CTEF formula, device training is no longer cost effective when the CTEF crosses the point corresponding to the ratio of cost/hr on the device to cost/hr on the actual equipment. For their hypothetical flight data, Roscoe and Williges (1971) estimated that the cost rates to be approximately \$16/hr and \$24/hr for the simulator and the actual aircraft, respectively, resulting in a ratio of about 0.67. Referring back to Figure 1, the CTEF crosses that ratio at about 11 hours. According to these results, then, a maximum of 11 hours of simulator training can be substituted for 11 hours of flight training without losses in proficiency.

Holding (1977) maintained that his index of transfer effectiveness can be used to integrate cost information by simply converting training time on the media to costs. Then total costs (sum of costs on the device and actual equipment) are plotted as a function of device training time. The top curve of Figure 2 presents this total cost function using the transfer data and estimated cost rates provided by Roscoe and Williges (1971), that is, \$16/hr and \$24/hr for the simulator and the actual equipment, respectively. This function can be interpreted in a manner similar to the previous total time function shown in Figure 1. That is, training with the device is no longer cost effective when total costs exceed the value for training using the actual equipment alone. As can be seen in Figure 2 and in agreement with the CTEF analysis, that point occurs at about 11 hours of training.

The total cost function in Figure 2 describes all possible mixes of training on the device and actual equipment that maintain a criterion level of performance. This function illustrates that the strategy of continuing to use a device until no longer cost effective is not an optimal allocation solution. That is, there are mixes where the device is used less than 11 hours and the total costs are less than the costs of using the actual equipment alone. Bickley (1980) reasoned that the optimal allocation of training on a device and on actual equipment is that point where total costs are at a minimum. To



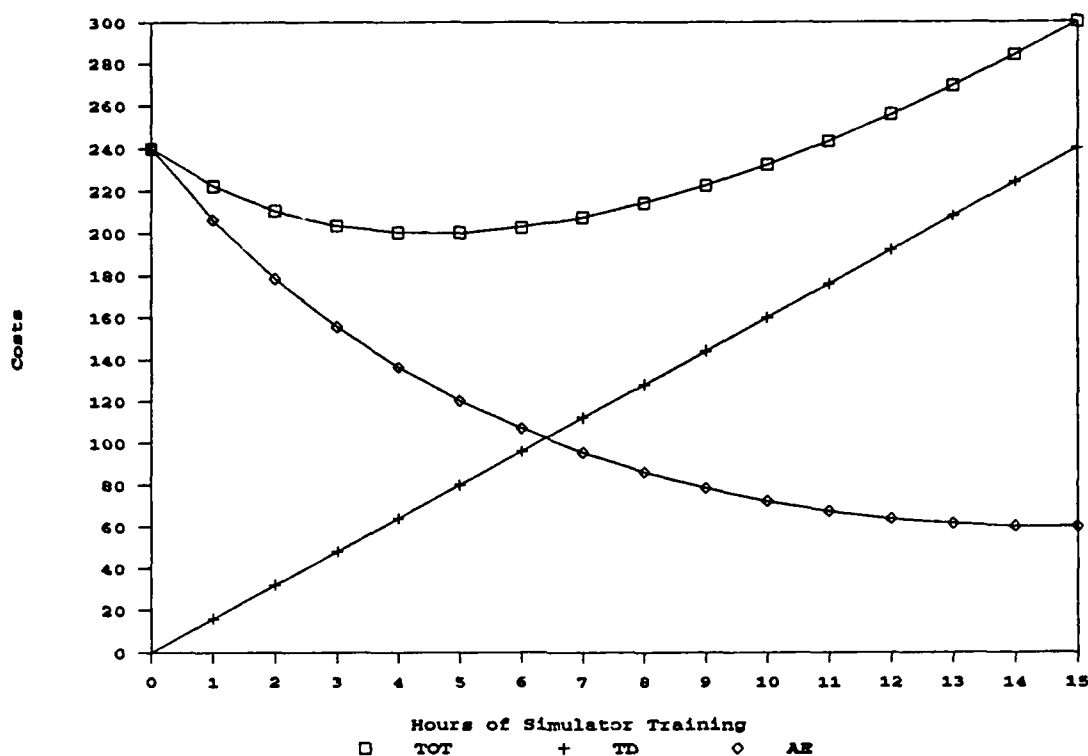


Figure 2. Components of the total cost function. (TOT = total costs, TD = costs associated with training device, AE = costs associated with actual equipment.)

develop a method for determining the minimum point, Bickley first decomposed the total cost function into two component functions: (a) the function relating costs associated with device training to device training time, and (b) the function relating costs associated with training on actual equipment as a function of device training time. (These two components are shown in relation to the total cost function in Figure 2.) The first relationship is a simple linear function that describes the cost rate of the training device. The second relationship is sometimes referred to as an "iso-performance" function because it describes the tradeoff between device and actual equipment costs required to maintain performance at some given level. Bickley showed that this iso-performance is satisfactorily fit by a decreasing exponential function of the form

$$y = a e^{-bx} + c \quad (3)$$

where  $y$  = amount of training in actual equipment required to reach performance criterion,

$x$  = amount of simulator training, and

$a, b, c$  = positive constants that are parameters of the model.

Given the form of the two component functions, Bickley was able to derive the formula for the total cost function. Using simple calculus, he then derived a formula for calculating the amount of device training that minimizes the total costs. Referring to Figure 2 again, it can be seen that that point is graphically between four and five hours of training on the device.

Bickley's (1980) approach to determining the optimal allocation of training time minimizes costs for a given performance level. In contrast, Carter and Trollip (1980) developed methods for optimally allocating training time such that performance is maximized given fixed training costs. This solution also is also based on an iso-performance function; however, Carter and Trollip used a hyperbolic form that was much simpler than the exponential formula assumed by Bickley. The user must specify the constraints of his/her budget as the amount of dollars available for training and the relative costs of the media. For instance, suppose \$2000 were available for gunnery training with training on actual equipment costing \$500/hr and training on a computer-based device costing \$50/hr. Expressing these constraints as an equation,  $50A + 500B = 2000$ , it can be seen that different sets of training time allocations can satisfy the constraints (e.g., 0-4, 10-3, 20-2, 30-1, 40-0). Carter and Trollip then showed that the Lagrange multiplier technique, which was developed for use in constrained maximization problems in microeconomic theory, can be used to determine that unique set of training time allocations that yields maximum performance. Despite the apparent differences between the cost minimization approach described by Bickley and the performance maximization approach presented by Carter and Trollip, Cronholm (1985) demonstrated that the two approaches resolve to identical allocation solutions. The only difference between the optimal solutions is the criterion for halting training: under the cost-minimization solution, training on the actual equipment is halted when performance on the actual equipment reaches the performance standard; Under the performance maximization solution, training is halted when budgetary resources are exhausted (Sticha, Singer, Blacksten, Morrison, & Cross, 1988).

Evaluation. Three different methods were discussed for allocating training time. The first method, implicit in the analyses described by Roscoe (1971) and Holding (1977), is to use a training device (or any lower cost training alternative) until it is no longer cost effective. The second approach (described by Bickley, 1980) is to allocate time to the training device to achieve a fixed standard of performance such that total training costs are minimized. The third approach (described by Carter & Trollip, 1980) is to allocate training time given a fixed total training budget such that performance is maximized. The analysis by Cronholm (1985) suggests that the two latter strategies may, in fact, yield identical allocation solutions. There is no preferred approach: The relevance of the three methods to gunnery training depends on the intentions of the training strategy designer.

#### Collection of Transfer Data

The techniques for measuring transfer are conceptually straightforward. It is telling that the techniques are often demonstrated on imaginary data sets such as the hypothetical data generated by Roscoe (1971). The major impediments to measuring transfer are the practical problems related to collecting transfer data. The crux of this problem is the requirement to measure transfer at more than one level of device training. The following

paragraphs describe alternative methods that have been suggested for obtaining such data.

Method. If level of training is manipulated between groups, the required number of subjects becomes a crucial problem. Two studies that have derived transfer functions used three experimental groups of subjects corresponding to different levels of training plus a fourth no-training control group (Bickley, 1980; Pouvenmire & Roscoe, 1973). This design allows the determination of four points on the transfer function, which probably represents the minimal requirement for estimating such functions. On the basis of a power analysis of gunnery performance measures, Morrison (1988) estimated that 12 crews, or a single armor company, is the minimal sample size required for parametric statistical comparison of mean differences. Assuming four samples, this implies that this transfer design would require 48 crews, or all the crews in a single battalion. For determining a single transfer function, this data collection requirement may be unreasonable. One approach to increasing the precision of the estimate between training time and performance (and thereby reduce data requirements) is to obtain initial performance on the training device. If this performance were correlated with performance on the actual equipment, statistical methods could be used to control for differences among crews in their initial (pretraining) performance levels.

The between-groups design used by Pouvenmire and Roscoe (1973) and by Bickley (1980) may be characterized as a traditional experimental design where equal numbers of experimental units (here, crews) are assigned to a fixed number of conditions. This design is optimal for techniques that estimate mean differences (e.g., analysis of variance) because it maximizes statistical power and inoculates the results against violations of parametric assumptions. However, this design may not be appropriate for nonlinear regression analyses whose purpose is to estimate functions, not means. To estimate such functions, data points should be concentrated about the critical portions of the function (e.g., inflection points) thereby reducing the standard error at those points. For total time or cost functions, the critical portion would be around the minimum point of the function. It is conceivable that this design might be achieved with fewer than the 48 crews prescribed by the traditional design. However, much more information is needed to provide sample size requirements for the optimal design. In particular, empirical research is needed to establish the minimum number of crews to satisfactorily fit a learning function, and the number of data points required to accurately estimate key parameters such as the minimum point of a total cost function.

Boldovici (1987) suggested an alternative to the between-group design wherein amount of training is manipulated within-groups. Boldovici's design requires an experimental group to alternate between training and testing so that they are repeatedly tested, at different points in learning. A second control group receives only the multiple test trials without the intervening training trials. The repeated measures design controls for repeated testing, an important threat to internal validity of the design (Campbell & Stanley, 1966). Internal threats to validity are those design flaws that confound treatment effects with other effects (e.g., testing effects) and therefore seriously compromise the interpretation of the results. By including a control group that receives the test trials but not training, Boldovici's design allows the researcher to control for and evaluate the effects of

testing apart from the effects of training. That is, transfer would be measured as the difference between the experimental group and control group at each point in training. Boldovici also pointed out that the multiple test trials in the control group allows the experimenter to calculate the reliability of the test performance measures.

A shortcoming of the repeated measures design is that it does not control for the interaction of testing with training. Campbell and Stanley (1966) identify this interaction as a potential threat to external validity. A threat to external validity is one that limits the generalizability of the effects. This particular external threat (interaction of training and testing) is present whenever the test somehow affects or sensitizes subsequent treatments, that is, the interpolated training trial. This interaction is quite possible in the present transfer design where training and testing occur in different media. In fact, one of the sequencing principles (6.1) discussed earlier asserts that performance is enhanced by alternating between different training devices. In other words, the act of testing on some high fidelity medium (e.g., the actual equipment) may enhance the effects of subsequent training on a low fidelity alternative. This generalizability of the transfer effect is thereby limited to those situations where training on devices and actual equipment is alternated exactly as prescribed in the experimental design. However, practical considerations would probably proscribe against this iterative approach. The more traditional approach is to train with the lower-fidelity alternative and then shift (once) to the higher-fidelity medium. Assuming that this interaction exists, an experimenter would overestimate the transfer between devices if he/she (mistakenly) tried to generalize the results from a repeated measures design to the traditional training strategy.

This line of argument points out that the "traditional" approach to training may not be the optimal strategy in that it does not allow the transfer potential of the devices to be fully realized. Thus, the interaction of training and testing may be viewed as a training strategy as well as a design issue in transfer of training. To determine the extent of this interaction, however, would require the addition of one or more comparison conditions wherein training and testing are not interspersed. This alternative approach unfortunately returns us to the problem that the repeated measures design was designed to address, that is, the excessive numbers of required crews.

Recognizing the severe data collection requirements for determining transfer functions through analysis of performance, some researchers have turned to using expert judgments as proxy measures for estimating transfer. Pfeiffer and Horey (1988) refer to a group of judgment-based techniques as "simulated transfer." To use this technique, personnel familiar with the operational task in question and the training device are asked a series of structured questions. First, they are asked to estimate the number of trials that are required to perform a particular task to criterion without the aid of a training device. Then given a fixed number of trials on the simulator, they are asked to estimate the number of additional trials on the actual equipment would be required to reach the same criterion after device training has occurred. From these data, an estimated transfer ratio can be calculated. To obtain a simulated transfer function, the expert must provide multiple estimates under given varying amounts of device training. Unfortunately, the

reliability of the transfer estimates has not typically been measured in these studies. Furthermore, the validity issue is moot given the lack of concurrent measures of actual performance.

Evaluation. Neither the performance-based nor the judgment-based approaches to determining transfer functions is completely satisfactory. The findings from the empirical performance-based approach (if properly executed) are unequivocal; however, the process of gathering the required data may be prohibitively expensive in terms of resources required to obtain and test numerous tank crews. On the other hand, the resources required to obtain expert judgments related to transfer are minimal; however, the results obtained may have questionable validity. There ought to be a middle ground wherein knowledge of empirical transfer phenomena (e.g., shape of the transfer function; cf. Bickley, 1980) can be used to improve expert judgment. In other words, instead of obtaining multiple CTER estimates, judges could be asked questions relating to the transfer function's parameters, such as its asymptote or rate parameter. The estimates could probably be made relative to other devices or objectives. The estimates could then be used to generate the functions. This approach is used in the OSBATS-based approach described by Blacksten (1989).<sup>3</sup> Even though this "enhanced judgment" approach appears reasonable, it has not been verified by comparison with actual transfer data or with other simulated transfer techniques.

#### Collection of Cost Data

Whereas the crux of the problem in collecting transfer data was the required soldier support, the essence of the problem in obtaining cost information itself relates to the nature of cost data. One definition of training cost is the value of important opportunities that a training consumer must forgo in order to avail themselves of training interventions (Levin, 1985). With reference to training allocation problems, this definition implies that the cost units must have at least three key characteristics. First, the costs should be relevant in that they measure values that impact the consumer of training. Second, cost units must possess certain minimal mathematical properties (e.g., ratio level measurement, commensurability of units) to allow the units reflect value in a mathematical sense. Third, the cost units should be sensitive enough to differentiate among the training interventions. Three approaches to measuring costs are discussed below in terms of these key characteristics.

Methods. Levin (1985) argued that total costs can be specified by identifying all the ingredients of a training intervention. These ingredients may be classified under general headings such as costs related to personnel, facilities, equipment, supplies, and so forth. Once all ingredients have been identified, the analysis proceeds to identify who incurs each cost. This breakdown allows the analyst to determine the "total" costs for each constituency. One of the central assumption to Levin's ingredients model is

---

<sup>3</sup>OSBATS is an acronym that stands for the Optimization of Simulation-Based Training Systems. Developed by Paul Sticha and colleagues for the Army Research Institute, OSBATS is a computer-based model for aiding simulator developers to design more effective training devices. For more detail on OSBATS, see Sticha, Blacksten, et al. (1988).

that the best estimate of the value of each ingredient is its market price. Techniques are suggested for estimating the market price for each of the different categories of ingredients. This technique directly addresses the second characteristic of costs (the mathematical properties) by expressing values in a common physical scale, such as in dollars and cents. This approach is also very sensitive to differences between training media. On the negative side, defining costs in terms of dollars and cents may be misleading in some instances.

Edwards (1987) cautioned decision analysts against using dollars and cents exclusively in measuring perceived value (i.e., utility). He argued that monetary terms may be appropriate to some variables but not others. Consider the example of training from the viewpoint of a military unit commander. Nonmonetary costs of training interventions include variables such as the relative availability of the media or the logistical problems of getting to and from training sites. He might also consider the unit personnel support required to operate the media. However, the personnel costs expressed in purely monetary terms would not be appropriate because the commander is not directly accountable for these. More relevant cost measures for personnel support include the degree to which certain types of personnel can be replaced by another type. For costs that do not have physical scales, the alternative is to develop subjective scales using psychophysical scaling techniques. The advantage to subjective scales is that they can be tailored to correspond to costs that are relevant to the user. However, subjective scales may not be commensurable with other costs on physical scales of measurement. One possible approach for combining physical and subjective measures (even multiple subjective measures) is through the use of MAUT techniques discussed previously. The difference is that previously we used MAUT to combine utility measures; here, MAUT could be used to estimate and combine cost measures.

The Army has recently focused much attention on a single cost dimension that may prove useful in solving some of these problems. Operating tempo (OPTEMPO) is presently defined in terms of miles per unit time expended by combat vehicles. By making unit commanders directly accountable for this training resource, this variable is, by definition, a relevant cost factor. Another advantage to OPTEMPO is that actual mileage plus certain other automotive expenditures (e.g., maintenance) get converted into a single metric, miles. The only problem with using OPTEMPO as the sole cost measure is that it may not be sensitive to certain cost differences among training media. For instance, OPTEMPO would distinguish between tank-appended devices that consume significant OPTEMPO resources and computer-based devices that consume no OPTEMPO. However, the OPTEMPO measure would not differentiate among alternatives within those two categories. If OPTEMPO were the only significant cost factor, then this insensitivity would not pose a problem, that is, the alternatives within categories would not differ in costs.

Evaluation. Three approaches to measuring costs were discussed: (a) determination of market prices, (b) estimates of more subjective measures of costs, and (c) use of the Army's concept of OPTEMPO. Neither of these cost measures was entirely satisfactory for gunnery training applications. Perhaps the best approach to take is a comprehensive one where the analysts attempts to identify all costing ingredients as prescribed in the method proposed by Levin (1985). In contrast to Levin's approach, however, the ingredients should not consist exclusively of financial variables. The problem of

commensurability may be addressed by transforming all variables to a common subjective utility metric.

#### Summary of Recommendations for Allocating Training Time

In summary, the quantitative methods for allocating training time on the basis of cost effectiveness are relatively unambiguous applications of mathematical technology and present no serious problems of interpretation. However, the use of these methods requires valid transfer and cost data. The collection of empirical transfer data is particularly fraught with logistical and design problems. One solution to these problems is to derive "simulated" transfer functions from subject matter experts who are partially aided by our knowledge of the functions parameters. However, research is needed to determine the extent to which the estimates correspond to actual performance. The problem with cost data reduces to the question: What is a cost? Alternative definitions were offered, each with advantages and disadvantages. The recommended solution was to obtain the most comprehensive measures of cost and examine methods for combining these variables.

#### Application of Training Strategy Methods

In the previous methods section, the training strategy procedures were described in the abstract so that they have some generality to a range of problems. The purpose of the present applications section is to make these methods more concrete by using them to two selected aspects of the domain of training objectives identified by Morrison et al. (1990). These two cases were chosen to be sufficiently different from one another to demonstrate the generality of the methods. The aspects were also chosen to illustrate prototypical training problems that confront training managers. In the first case presented below, the methods are applied to the problem of specifying how devices that significantly differ in fidelity and costs can be used to train similar skills. In the second case, the methods are used to determine how devices can be used to train dissimilar skills.

As previously discussed, the heuristics related to sequencing and structuring training are dependent on the analyst's knowledge of the subject matter (i.e., armor gunnery) and of training. In other words, the application of the techniques were executed without relying on external data sources. In contrast, the algorithms related to device selection and allocation of training time required external data. For the latter two groups of methods, hypothetical data were generated to illustrate the application of the methods. These data were hypothetical in the sense that they were not obtained from recommended data sources, such as actual performance or expert opinion. However, a conscious effort was made to approximate the data that would be obtained from those sources.

#### Training Similar Skills with Different Devices: Using VIGS and I-COFT to Train Target Engagement Skills

For many domains such as armor gunnery training, both high- and low-fidelity training devices overlap in their training function: that is, they train a common set of skills. The issue discussed in this section is how to integrate training so that both types of devices are used to their best advantage. For tank gunnery training, two different computer-based devices

have been prescribed for institutional training: the Videodisc Gunnery Simulation (VIGS) and the Institutional Conduct-of-Fire Trainers (I-COFT). The VIGS is an inexpensive tabletop simulation system consisting of a low fidelity representation of the gunner's station, a laser videodisc player for presenting target images, and a micro-computer for controlling the simulation. VIGS does not simulate any aspect of the tank commander's station. The I-COFT is a special version of the core simulator: the Unit Conduct-of-Fire Trainer (U-COFT). In training capabilities, the I-COFT is very similar to the U-COFT in that they are both high-fidelity and (relatively) high-cost, computer-based trainers. In contrast to the VIGS, the I-COFT has the capability to train tank commanders as well as gunners.

The training objectives for this example were taken from the cluster of subtasks related to target engagement identified by Morrison et al. (1990). These subtasks were similar in that most required psychomotor skills and a high fidelity representation of internal tank controls and external visual scenes. This cluster explicitly excludes subtasks related to target acquisition. For the present example, the objectives included only the subtasks that are those related to precision (nondegraded) mode using the main gun. Using these criteria, nine subtasks were identified and are listed in Table 4. These objectives will be used to illustrate methods related to three of the four problems addressed by training strategies: structure, sequence, and allocate training. For the present example, the device selection problem is not relevant because the devices (VIGS and I-COFT) are "givens" in the problem. Despite that fact, it is a useful first step in developing a training strategy to systematically evaluate the capabilities of both devices.

#### Evaluate Device Capabilities

The capabilities of VIGS and I-COFT to train gunnery engagement subtasks are summarized in the last two columns of Table 4. This information was adapted from a detailed evaluation of computer-based gunnery training devices (Hoffman & Morrison, 1988; Morrison & Hoffman, 1988). The devices were evaluated using a simple three-category scheme that describes the extent to which devices represent conditions and actions associated with each subtask: (a) a high fidelity representation, (b) a low fidelity representation, or (c) no representation. As can be seen in Table 4, VIGS is a lower fidelity device in two senses. It is less comprehensive than I-COFT in that it provides no opportunity for training certain aspects of gunnery, such as the TC training objectives. For the subtasks that it does train, it is also less realistic than I-COFT. For instance, not all the switches at the gunner's control panel are represented in the VIGS as they are in the I-COFT. On the basis of this analysis alone, it would appear that the I-COFT is the preferred alternative for training target engagement skills. However, the purchase cost of VIGS is markedly lower than I-COFT: In 1988, Witmer estimated that VIGS sold for about \$40,000, whereas the U-COFT cost nearly 50 times that amount or \$1,900,000. (The I-COFT is more even more expensive than the U-COFT due to its enhanced capabilities.) As a consequence, the Army can purchase more of the lower cost VIGS devices and make them more available for individual training. Thus, the applied research question should not be "which device is better?" Rather, the question should be "how can these devices be used to their best advantage in an integrated training strategy?" This question provides the central theme for applying the training strategy methods.



Table 4

## Summary of To-Be-Trained Subtasks and Device Capabilities

Subtask	Crewman Performing	Skill	Fidelity of Representation	
			VIGS	I-COFT
3.1.1. Issue standard fire command	TC	Cognitive	No	High
3.1.2. Lay gun for direction	TC	Psychomotor	No	High
4.1.1. Set switches per fire command	GNR	Procedural	Low	High
4.1.2. Identify specified target	GNR	Visual perception	High	High
4.1.3. Track target	GNR	Psychomotor	Low	High
4.1.4. Lase to target	GNR	Psychomotor	Low	High
4.1.5. Fire at target	GNR	Psychomotor	Low	High
4.2. Maneuver tank	DVR	Psychomotor	No	No
4.3. Load round	LDR	Gross motor	No	No

Structure Training

The subtasks listed in Table 4 are relatively homogeneous with respect to skills and fidelity requirements. On the other hand, the numerous subtasks in this cluster represent core gunnery skills that must be well learned. A key question in this problem is whether this cluster should be considered a single instructional unit, or subdivided into multiple units. On the basis of the complexity of the target engagement task, it was decided to break the unit down further. In other words, a part-task strategy was to prescribe training on this gunnery task. Taking this as a working assumption, the next problem was to identify the parts. Paraphrasing the previous guidelines in the methods section, two general guidelines for partitioning training can be derived: (a) sequentially related subtasks can be trained apart if they are temporally distinct and refer to different subgoals, or (b) nonsequentially related subtasks can be trained apart if the underlying skills requirements are substantially different. The following paragraphs detail how these two guidelines apply to target engagement.

Two subtasks in this cluster are different from the others by virtue of the fact that they are tank commander actions: issue fire command (3.1.1) and lay gun for direction (3.1.2). These two actions occur practically

simultaneously raising the issue of whether they should be trained separately or together. A rational analysis of skills indicates that the former subtask is primarily cognitive and verbal in nature, whereas the latter is primarily psychomotor. According to Wicken's (1989) taxonomy, these two subtasks require substantially different attentional resources. Therefore, they can be trained apart from other subtasks in this cluster and apart from one another.

The subtask related to setting switches (4.1.1) occurs after the fire command and prior to tracking. Furthermore, the skills and fidelity requirements related to this subtask are qualitatively different from other subtasks within this cluster. Similarly, the subtask related to target identification (4.1.2) is a temporally distinct action. It is also different in a skills sense, involving perceptual and verbal as opposed to manual response processes. Thus, both of these subtasks can be trained separately from the others in this cluster. In contrast, the track, lase, and fire subtasks (4.1.3, 4.1.4, and 4.1.5) are described as interrelated behaviors performed in sequence. They are interrelated by virtue of the fact that the behaviors overlap and can be performed out of sequence under some circumstances. For instance, the act of either lasing or firing can cause the gunner to lose the target track, requiring him to restart the sequence. In other words, these "sequential" skills are less sequentially related than a simple list of actions would indicate. Furthermore, all three subtasks require similar psychomotor skills, occur in close temporal proximity, and are related to a common goal (i.e., hitting the target). For these reasons, these subtasks should be trained together as a single unit.

Concurrent with the actions of the tank commander and gunner, the driver and loader perform related subtasks: maneuver tank (4.2) and load round (4.3). As can be seen in Table 4, these objectives are not trained by either simulator, and are therefore not considered in the present example. Thus, training on these objectives cannot be accomplished on these two simulators. Because these subtasks are no longer considered, they were not broken down into lower level subtasks as they were presented in Morrison et al. (1990).

In summary, the analysis indicated that the subtasks related to target engagement can be rationally decomposed into parts for training. At the same time, the parts are clearly related to a common task goal (successful engagement of targets) and should be reintegrated in a common unit of instruction. In training development terms, the common training unit addresses some terminal training objective related to the attainment of whole-task gunnery skills. In turn this objective would be divided into intermediate training objectives corresponding to each of the parts identified above.

### Sequence Training

The first sequencing consideration is how the unit of instruction on target engagement relates to other units of instruction on gunnery. In that regard, the present unit is designed to train prototypical gunnery skills, those required to execute the simplest gunnery engagements such as those having only a single main gun target fired under nondegraded mode conditions. Accordingly, this unit should precede other units that concern target engagements under special circumstances, such as multiple targets, machine gun

engagements, and degraded mode gunnery. This sequence is prescribed by a number of rules described in the methods section, in particular, rule 1.3 (Use progressive elaboration) and rule 4.2 (Progress from easy to difficult).

The actions within the engagement cluster are typically performed in a fixed order. Therefore, according to sequence rule 2.1 (Follow job performance order), the subtasks within this unit should be sequenced in the order that they are performed. However, the extent to which this rule may be carried out is limited by device capabilities. That is, if training is begun with VIGS, the first two subtasks related to the fire command (3.1.1) and initial target lay (3.1.2) cannot be trained. One way to alleviate this problem is to provide off-line (i.e., non-device-based) verbal instruction on fire commands since this subtask is cognitive/verbal in nature and does not require a simulator for training. Off-line training on fire commands could also be provided in conjunction with training on gunner control switches (4.1.1) and target identification (4.1.2). More problematic is the subtask concerned with training the commander to provide the initial target lay (3.1.2). Because this psychomotor skill requires simulation of a target and control handles, it would not be effectively trained by verbal methods. Because the VIGS does not simulate the tank commander control handle, the only alternative is to train this subtask on the I-COFT.

At this point, it is useful to summarize the results from the application of the methods related to both structuring and sequencing training. Figure 3 indicates that three subunits can be identified for this cluster of subtasks. The lowest level is off-line verbal instruction on three subtasks not addressed by VIGS. The instruction is "off-line" in the sense that instruction is not in the context of one or the other training device. Also note that, for these relatively independent subtasks, no necessary instructional sequence is implied. The next level of instruction is provided by VIGS, wherein the student receives instruction in setting switches (4.1.1), identifying targets (4.1.2), and tracking/lasing/firing (4.1.3/4.1.4/4.1.5). These three groups of subtasks should be trained separately and in sequence. After initial instruction, however, the student should be able to practice all three subtasks as an integrated act. The final level of training on the I-COFT integrates tank commander actions with the gunner actions presumably acquired in the VIGS. Note that instruction at this level should emphasize the initial lay (3.1.2) because this is the first opportunity for the tank commander to practice this act.

Given the structure of training and sequencing within the three subunits of instruction corresponding to the three media (verbal instruction, VIGS, and I-COFT), the next step is to specify the sequences among the subunits. Review of the sequencing principles reveal two different strategies could be taken. Perhaps the more obvious approach is to follow the crawl-walk-run principle (Rule 3): (a) Start with off-line verbal instruction, (b) proceed to training with VIGS, and (c) end with training on the I-COFT. The other approach would follow the principle of alternating devices (Rule 6), which suggests that alternating practice with different devices may enhance learning. Thus, alternating between VIGS and I-COFT for several iterations might produce more learning than simply moving from the lower- to the higher-fidelity device. To determine whether the alternation sequence is superior to the more commonly accepted notion, research should be performed that compares these two sequencing strategies while strictly controlling amount of training. However,

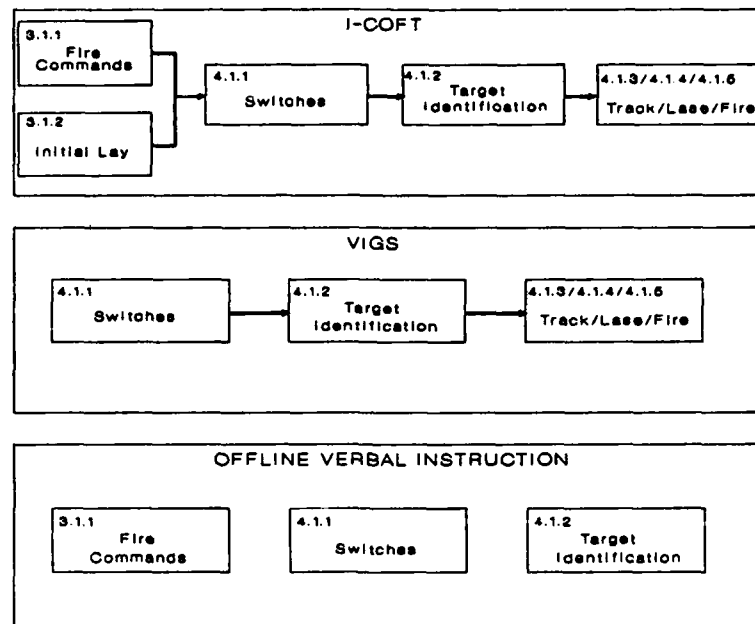


Figure 3. Summary of structure and sequencing strategy for using VIGS and I-COFT to train gunnery engagement.

it is clear that the former strategy (i.e., train on VIGS, then transfer to U-COFT) would probably cause fewer logistic problems in scheduling training and access to devices than alternating back and forth between the two devices.

### Allocate Training Time

For the purposes of illustrating the allocation of training time, the present example assumes the simpler sequencing strategy detailed in the immediately preceding paragraph. As discussed in the methods section, the allocation of training time requires two types of external data: transfer function of skills between VIGS and I-COFT and the relative costs of the two devices. The transfer data requirements are discussed in the paragraphs below, followed by an illustration of how cost information can be integrated with the transfer data to allocate training time.

Two research studies have investigated transfer from VIGS to U-COFT with differing results. Witmer (1988) failed to demonstrate reliable transfer from VIGS to U-COFT or from U-COFT to VIGS. On the other hand, Turnage and Bliss (1989) demonstrated that skills learned on low fidelity trainers (VIGS and another device, TopGun) transfer to I-COFT. However, their results confounded the effects of training on VIGS with the effects of training on TopGun. More importantly, neither Witmer nor Turnage and Bliss systematically varied the amount of VIGS pretraining as an independent variable. Thus, neither study provided data sufficient to derive a transfer function of skills learned on VIGS to I-COFT.

Without actual transfer data, it was necessary to create hypothetical data to illustrate the methods related to this problem. These data would be

obtained from the following experimental design: A control group would receive training on the I-COFT alone while at least three experimental groups would receive differing amounts of pretraining on VIGS prior to I-COFT training. As Bickley (1980) pointed out, the determination of appropriate amounts of pretraining for the experimental groups is not a trivial design detail:

If all three independent variable values chosen are too large, then the resulting dependent variable values will all lie in the asymptotic portion of the curve, and inferences about the descending portion of the [iso-performance transfer] curve may lack precision. On the other hand, if all three values chosen are too small, then the dependent variable values will all lie in the descending portion of the curve, and inferences about the magnitude of the asymptote may lack precision (pp. 9-10).

Given the constraints in institutional gunnery training and some knowledge of the effects of VIGS training, a plausible set of values for amount of pretraining for three experimental groups would be two, four, and eight hours. This would correspond to one-quarter, one-half, or a full day's practice on VIGS. These hypothetical data represent information that could have been obtained from the results of a transfer experiment or from estimates of those data using the "simulated transfer" techniques described in the methods section. The present data were generated by our research staff who were familiar with the capabilities of the two devices and their effects on performance. It should be stressed that the purpose of these data was not to provide descriptions of the transfer relationships that actually exist between devices; rather, the purpose of these data was to illustrate how such information could be used to allocate training time.

The hypothetical transfer data are presented in the top row of Table 5. Data from the control group (zero hours pretraining) indicate that it takes an average gunner about 8 hours (all day) to learn to execute some sort of engagement or a related set of engagements to some criterion of acceptable performance. Data from the experimental groups indicate that the time to reach criterion on I-COFT is inversely related to increases in VIGS pretraining. This function also shows the negatively accelerated shape that Roscoe (1971) noted was typical of skill transfer. The second row in the table (total time) indicates that two hours of VIGS pretraining effectively saves about one hour of total training time. Thus, if training on the VIGS and I-COFT were equally costly, the optimal mix that minimized total training time would be two hours of pretraining on VIGS followed by (approximately) five hours of training on I-COFT.

As argued previously, however, the costs related to VIGS and I-COFT are not equal. Witmer (1988) estimated that the procurement costs of U-COFT are 50 times greater than those of VIGS. It was also noted that procurement costs only indirectly affect costs incurred by the unit. The effect is indirect in that, because VIGS is cheaper, it can be made more available. The general fielding strategy calls for VIGS to be made available at the company level, whereas some version of COFT will be provided at the battalion level. A very gross estimate of the relative availability of VIGS and I-COFT therefore is 4 to 1, respectively, based on the relative number of devices dedicated to a

Table 5

Findings from Hypothetical Research Measuring Transfer from VIGS to I-COFT

	Hours on VIGS			
	0	2	4	8
Required Hours to Reach Criterion on I-COFT	8.0	5.1	4.3	4.1
Total Time (Hours)	8.0	7.1	8.3	12.1
Total Relative Costs <sup>a</sup>	32.0	22.4	21.2	24.4

<sup>a</sup>Total Relative Costs = (I-COFT hours X 4) + VIGS hours.

battalion. There are clearly other costs related to using VIGS and I-COFT such as the support required and logistics related to getting personnel to and from training facilities. Nevertheless, for the sake of simplicity in the present example, cost rates were defined exclusively by this gross estimate of relative availability of the devices. The last row in Table 5 displays total costs related to the experimental devices using these relative cost estimates. The results show that, given these cost estimates, the VIGS continues to cost-effectively substitute for I-COFT at even eight hours of VIGS training. This conclusion is based on the fact that the total cost of training at that point (24.4 "units") is still less than the cost of training to criterion on the I-COFT alone (32.0 "units"). However, if the strategy is to minimize total costs rather than substitute VIGS for I-COFT, a VIGS/I-COFT mix of (about) four hours on the VIGS and 4.1 hours on I-COFT appears optimal.

As a final note, this example assumes that performance is measured using some overall composite measure. Although there may be some merit in measuring overall gunnery performance using some composite measures (cf. Hoffman & Witmer, 1989), component measures of performance outcome and other behavioral process measures provide more detailed information about performance on individual subtasks. (Suggested measures are provided in Appendix A of Morrison et al., 1990). However, these lower level measures may generate substantially different transfer functions than the overall composite measure. The point to this digression is that the solution to the allocation problem may differ depending upon the exact objective (i.e., subtask) that is being targeted for training.

#### Training Dissimilar Skills with Dissimilar Devices: Using Various Devices to Train Platoon-Level Gunnery Skills

As in the previous example, the training objectives are defined at the subtask level. In contrast to target engagement skills, the subtasks related to platoon-level collective training are heterogeneous in nature. Table 6 lists these subtasks, which were identified by Morrison et al. (1990). Furthermore, a variety of both computer-based and tank-appended devices have

Table 6

Platoon Collective Subtasks

---

1. Travel in Platoon Formation
    - 1.1. Execute a Wedge Formation
    - 1.2. Execute an Echelon Formation
    - 1.3. Execute a Line Formation
    - 1.4. Execute a Vee Formation
    - 1.5. Execute a Column or Staggered Column
  2. Execute Battle Drills
    - 2.1. Execute Action Drill
    - 2.2. Execute Contact Drill
    - 2.3. Execute Air Attack Drill
  3. Bound by Section
  4. Overwatch a Bounding Platoon
  5. Occupy a Battle Position
    - 5.1. Occupy Initial Battle Position
    - 5.2. Occupy Subsequent Battle Position
  6. Maneuver Within a Battle Position
  7. Employ Fire Patterns
    - 7.1. Employ Frontal Fire
    - 7.2. Employ Cross Fire
    - 7.3. Employ Depth Fire
  8. Employ Firing Techniques
    - 8.1. Employ Observed Fires
    - 8.2. Employ Alternating Fires
    - 8.3. Employ Simultaneous Fires
- 

Note. Taken from Morrison, Meade, and Campbell (1990).

been developed to train these objectives. Thus, this example is good for illustrating the methods related to selecting devices, structuring training, and sequencing training. Although the methods for allocating training time are not well-suited to this multi-task, multi-device example; the other remaining three groups of training strategy methods can be applied to this second example.

Select Devices

As concluded in the methods section, the MAUT approach is the method of choice for selecting training devices. The MAUT-based device selection methodology can be decomposed into four steps: (a) formulate an initial list of training devices, (b) select attributes/describe devices, (c) weight the

attributes according to training objectives, and (d) calculate utilities of the training devices. Each of these steps is described by example below.

Formulate an initial list of training devices. The first step of this MAUT analysis is to identify devices that may apply to the training problem. With regard to the present example, five different training devices either in current use or in product development were identified as being relevant to training platoon-level collective subtasks. The first two are stand-alone, computer-based training devices, whereas the remaining three are tank-appended training technologies. Each of the five training devices is briefly described below.

1. Simulated Networking (SIMNET). SIMNET is a large-scale research project in interactive networked simulation sponsored by the Defense Advanced Research Project Agency (DARPA) and the U.S. Army Training and Doctrine Command (TRADOC). SIMNET provides for free play scenarios of tactical situations on a computer-generated simulation of the battlefield. It includes simulator stations for a number of different types of fighting vehicles including M1 tanks. The M1 stations consist of a driver's compartment and station and a crew compartment with gunner, loader, and commander stations. The stations are basically low fidelity representations of their counterparts on the actual equipment, and do not allow crewmembers to practice all aspects of crew gunnery. For instance, SIMNET does not simulate tank machine gun effects for either the coaxial machine gun or the commander's weapon. For more details on SIMNET gunnery training capabilities, see Hoffman and Morrison (1988).
2. Platoon Conduct of Fire Trainer (P-COFT). P-COFT is a developmental project that currently exists in prototype form as the UT-12. P-COFT extends the technology developed for the Unit-Conduct of Fire Trainer (U-COFT). The crucial distinction between the devices is that whereas the U-COFT was developed for training crew gunnery skills, P-COFT addresses gunnery skills in a platoon context. Like U-COFT, each of the four individual P-COFT compartments consists of gunner and tank commander stations only. In contrast to SIMNET, however, the gunner and tank commander stations are high fidelity representations of their counterparts on the M1 tank, and simulate most of its functions. A notable limitation of P-COFT is that tactical movement is strictly limited. Like the U-COFT, movement occurs at constant speed along preprogrammed routes; tank commanders can control movement only to the extent that they can start and stop the tanks. The computer-generated terrain for the prototype UT-12 represents a typical Table XII range (Range 301, Grafenwöhr) consisting of four lanes with artificial defilade positions. Because the ultimate design of P-COFT is not known, the attributes of the UT-12 prototype were used to evaluate this technology.
3. Multiple Integrated Laser Engagement Simulation (MILES). Appended to actual tanks, the MILES system simulates weapons effects by transmitting a laser beam at targets equipped with MILES sensors that detect target hits. The principal advantage to MILES is that



crews use their own tanks to practice tactical engagements without the safety limitations inherent to live-fire ranges. However, the functional similarity of MILES to live-fire gunnery is limited by the fact that the laser beam is pointed precisely in the direction that the gun tube is pointed. In an actual precision engagement, the ballistic computer modifies the gun's aiming point in accordance with input data, for example, target range, ammunition, speed of target, ammunition. Therefore, the ballistic computer must be turned off for MILES engagements. This deviation implies gunner does not set switches, lase, and lead as he would in an actual precision gunnery engagement. Target hit effects are simulated by the flash and bang emitted from Hoffman devices that are appended to tanks. However, MILES provides no simulation effects for target misses. Another significant departure from fidelity is that the loader is not required to load actual rounds.

4. Precision Range Integrated Maneuver Exercise (PRIME). PRIME is a developmental project whose purpose is to automate a number of range events and to provide performance feedback to crews. PRIME incorporates a number of different technologies including an instrumented version of MILES (I-MILES). I-MILES identifies firing vehicles, allows the vulnerability of targets to be varied, and transmits both types of information for processing and interpretation in terms of target hits/kills. In addition to processing this information, PRIME monitors and controls other system events such as target up/down and the intervisibility of targets. The targets for PRIME are radio activated silhouettes equipped with Laser Target Interface Devices (LTIDs). Thru-sight video (TSV) provides the capability to record the sight pictures as seen through the gunner's primary sight or through the gunner's primary sight extension. In general, PRIME capabilities mirror those of MILES except in the area of indirect fires. Whereas MILES has capabilities for representing indirect fires, PRIME does not have this capability in its present configuration. For more details on the capabilities of PRIME, see Drucker, Campbell, Koger, and Kraemer (1989).
5. Subcaliber. The tank-appended Telfare (M179) subcaliber device simulates main gun effects by firing a Cal .50 machine gun coaxially mounted with the main gun at appropriately scaled targets. One of the principal advantages to this subcaliber device is that weapon effects can be clearly observed and used for aiming adjustments. On the other hand, the device does not replicate the obscuration associated with the main gun muzzle blast. Furthermore, the subcaliber round is slower than a main gun round, thereby making it unrealistically easy for the crew to visually follow the round. As with live-fire training using full-caliber ammunition, subcaliber firing is subject to range fan safety constraints.

Select attributes/describe devices. The next step in the device selection methodology is to select attributes upon which the devices can be evaluated. For this example, the attributes were defined as characteristics of a device that determine its relevancy for training certain objectives.

There are many possible device characteristics, but not all relate to training objectives. For instance, the capability to record and analyze data is a characteristic of both the P-COFT and PRIME. Even though this attribute may be helpful to the training process, the training objectives do not differ with respect to their requirement for such a characteristic. In contrast, the objectives do differ with respect to the types of fidelity required to practice the task. Hannaman (1984) identified such fidelity features for battle simulations in general. His list was modified to capture the similarities and differences among the present devices. To simplify the analysis, the attribute descriptions were defined as binary characteristics (present/not present). Twelve such attributes were chosen and were defined in terms of the following yes/no questions:

1. Defilade position. Can the simulated tank locate, enter, and leave a hull defilade and turret defilade position?
2. Control of movement. Can the crew vary the speed of movement and select the route for traversing the terrain?
3. Precision gunnery. Does the device simulate the precision fire control system?
4. Degraded gunnery. Does the device simulate range finder malfunctions or loss of stabilization?
5. Coaxial machine gun. Does the device simulate the M240 coaxial machine gun?
6. Commander's weapon. Does the device simulate the commander's caliber .50 machine gun?
7. Firing signature. Does the device simulate the firing signatures of enemy weapons systems?
8. Weapons effects for misses. Given a miss, does the device provide a realistic cue to the distance between the point of impact and the target?
9. Indirect fires. Does the system simulate the effects of indirect fires?
10. Company net. Does the device simulate communications outside the platoon (i.e., on the company command radio network)?
11. Obscurants. Does the device simulate reduced visibility conditions caused by obscurants such as smoke or fog?
12. Terrain. Are variations in terrain represented in the simulation?

These twelve attributes were then used to describe the fidelity of each of the five devices. The results are presented in Table 7. These results showed that P-COFT possessed the greatest number of fidelity attributes; SIMNET, the least; with the tank-appended technologies falling somewhere in between.

Table 7

## Descriptions of Training Devices with Respect to Fidelity Attributes

Attributes	Training Devices				
	SIMNET	P-COFT	MILES	PRIME	SUBCAL
1. Defilade Position	0	1	1	1	1
2. Control of Movement	1	0	1	1	1
3. Precision Gunnery	1	1	0	0	1
4. Degraded Gunnery	0	1	1	1	1
5. Coaxial Machine Gun	0	1	1	1	0
6. Commander's Weapon	0	1	1	1	0
7. Firing Signatures	1	1	1	1	0
8. Weapons Effects	1	1	0	0	1
9. Indirect Fires	1	1	1	0	0
10. Company Net	1	1	1	1	1
11. Obscurants	0	1	0	0	1
12. Terrain	1	1	1	1	1

Note. One (1) indicates that the device possesses the attribute, whereas zero (0) indicates that the device does not.

Weight attributes according to training objectives. Each of the 12 attributes was weighted with respect to its importance for training the 19 platoon-level collective subtasks shown in Table 6. A ratio weighting procedure described by Edwards (1987) was used to elicit these weights. According to this procedure, the attributes were ordered from most to least important and then the least important attribute was assigned a weight of 10. Each succeeding attribute was then assigned a weight by asking "how many times more important" was the attribute from the least important one. In describing this process, Edwards advised that the analyst should not strive for numerical precision; rather, he should strive for capturing the concept of importance. The final step was to normalize the weights by making them sum to 1.0. This process was repeated for each of the 19 platoon-level objectives. The results are shown in Table 8.

Table 8

## Weights of Fidelity Attribute for Platoon-Level Subtasks

Subtasks	Attributes <sup>a</sup>											
	1	2	3	4	5	6	7	8	9	10	11	12
1.1 WEDGE FORM	.014	.201	.115	.050	.101	.043	.029	.094	.022	.086	.072	.173
1.2 ECHELON FORM	.014	.201	.115	.050	.101	.043	.029	.094	.022	.086	.072	.173
1.3 LINE FORM	.015	.212	.106	.053	.121	.061	.038	.030	.076	.083	.023	.182
1.4 TRAVELING OVERWATCH	.070	.186	.109	.062	.078	.085	.124	.047	.016	.031	.039	.155
1.5 TRAVELING COLUMN	.015	.193	.119	.133	.037	.030	.059	.052	.044	.089	.067	.163
2.1 ACTION DRILL	.154	.185	.092	.054	.069	.046	.131	.031	.015	.062	.038	.123
2.2 CONTACT DRILL	.045	.195	.180	.090	.105	.053	.135	.030	.015	.075	.015	.060
2.3 AIR ATTACK DRILL	.077	.231	.092	.015	.023	.123	.031	.100	.015	.046	.062	.185
3.0 BOUND BY SECTION	.176	.200	.106	.094	.035	.047	.118	.029	.012	.018	.024	.141
4.0 OVERWATCH	.157	.046	.118	.092	.052	.065	.131	.039	.013	.098	.020	.170
5.1 OCCUPY INITIAL BP	.150	.165	.105	.090	.060	.068	.023	.030	.030	.053	.015	.211
5.2 OCCUPY SUB BP	.150	.165	.105	.090	.030	.023	.015	.045	.038	.075	.053	.211
6.0 MANEUVER IN BP	.159	.203	.087	.058	.022	.029	.101	.065	.014	.043	.072	.145
7.1 FRONTAL FIRE	.057	.043	.199	.184	.099	.092	.028	.085	.014	.021	.035	.142
7.2 CROSS FIRE	.057	.043	.199	.184	.099	.092	.028	.085	.014	.021	.035	.142
7.3 DEPTH FIRE	.057	.043	.199	.184	.099	.092	.028	.085	.014	.021	.035	.142
8.1 OBSERVED FIRE	.086	.043	.172	.155	.078	.069	.052	.103	.026	.017	.060	.138
8.2 ALTERNATING FIRE	.086	.052	.172	.155	.078	.069	.043	.103	.026	.017	.060	.138
8.3 SIMULTANEOUS FIRE	.100	.083	.183	.150	.133	.117	.042	.067	.017	.033	.025	.050

<sup>a</sup>Attributes are identified by numbers which are defined in the previous table and in the text.

Calculate utilities of the training devices. Multiattribute utilities were calculated for each of the training objectives (i.e., subtasks) using the SMART formula. The results are shown for groups of related subtasks in Figures 4 - 7. The four groupings (travel, position, drills, and firing) are based upon further analysis of the platoon-level subtasks identified by Morrison et al. (1990); this analysis is detailed in the next subsection.

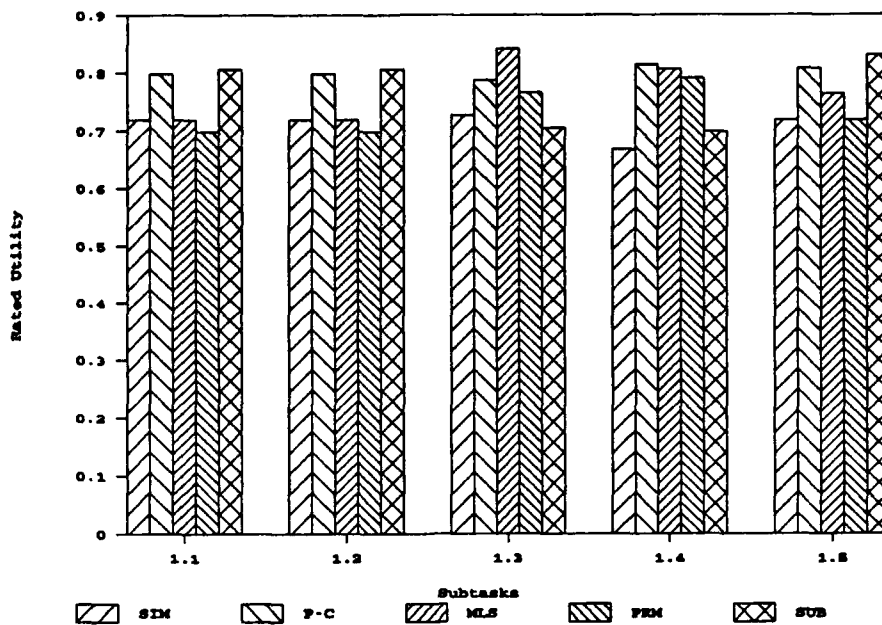


Figure 4. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to travel.

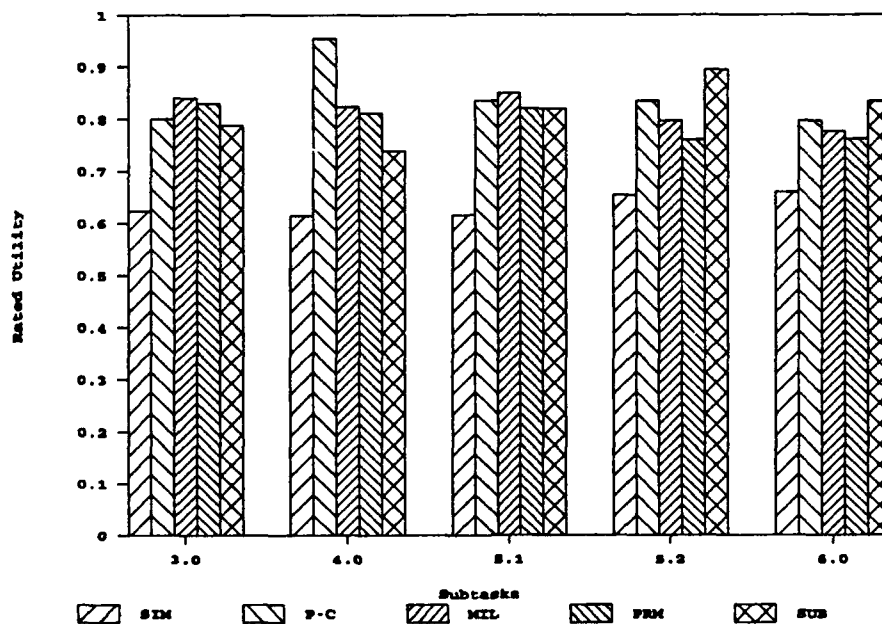


Figure 5. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to positions.

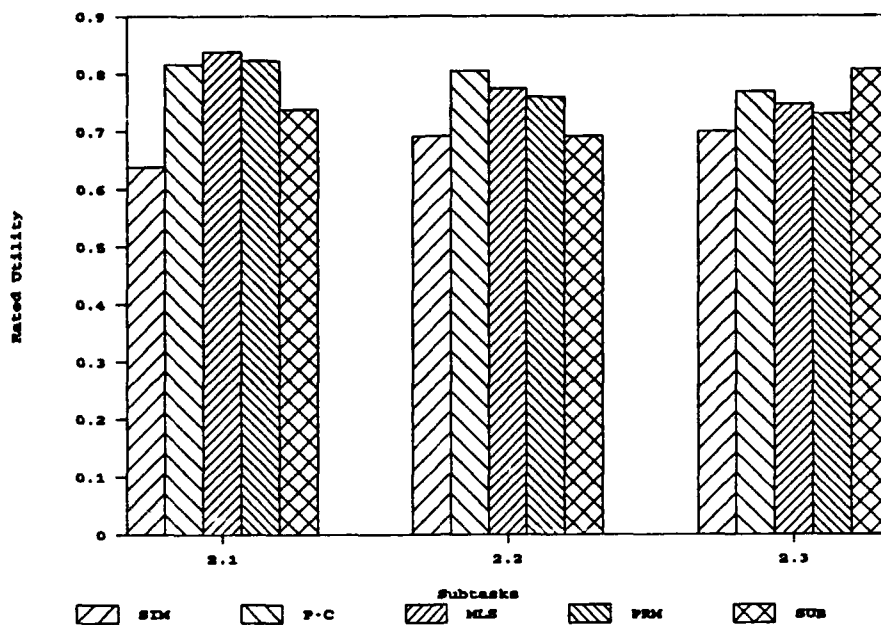


Figure 6. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to drills.

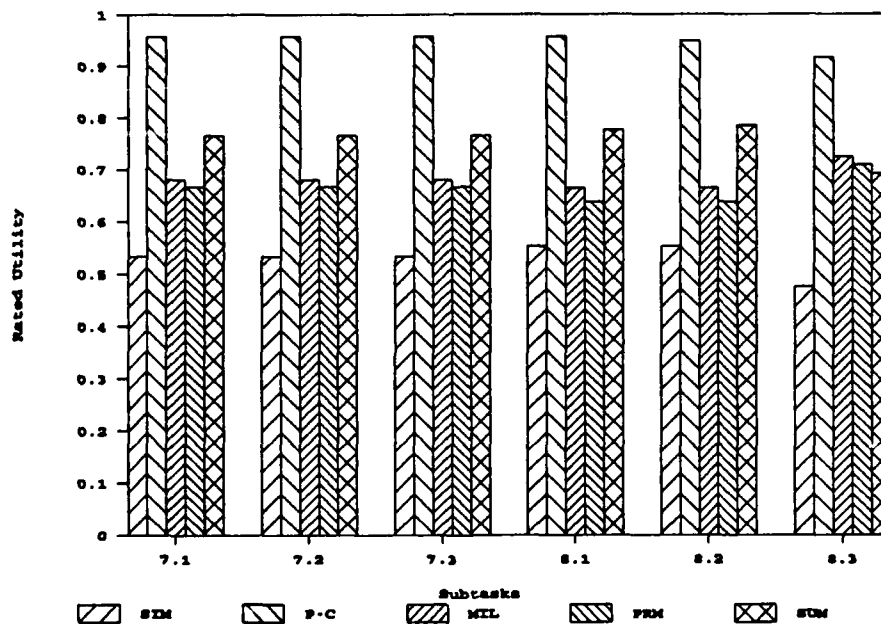


Figure 7. MAUT ratings of SIMNET (SIM), P-COFT (P-C), MILES (MLS), PRIME (PRM), and Subcaliber (SUB) devices for training subtasks related to firing.

The findings from the hypothetical MAUT analysis may be summarized by the following three points:

1. In general, SIMNET had the lowest utility of the five devices for training platoon-level collective gunnery. Out of that domain, SIMNET appears best suited for training related to the execution and control of movement formations. (See Figure 4.) Nevertheless, even for these subtasks, the rated utility of SIMNET was exceeded by that of both the Subcaliber device and P-COFT.<sup>4</sup>
2. For the objectives related to collective firing (Figure 7), P-COFT had the highest utility of all five devices. This is understandable in that P-COFT is designed to train such "pure gunnery" tasks. In contrast, the SIMNET and MILES devices were designed primarily to train tactics with gunnery simulated only at a rudimentary level. Had PRIME the capability to simulate precision gunnery,<sup>5</sup> it would have compared more favorably with P-COFT.
3. For the remaining objectives (Figures 5 and 6), the other four devices were rated fairly close in utility. Thus, according to this analysis, they are interchangeable. The reason that PRIME rated slight lower than MILES is its inability to simulate indirect fires.

The reasonableness of the results supports the contention that the MAUT-based methods were generally useful for systematically selecting training devices. The results also point to two specific difficulties. First, defining the utility of training devices in terms of fidelity features may be too constraining. This definition failed to capture the utility of certain instructional features such as the performance feedback and after action review capabilities inherent in SIMNET and PRIME. The problem in including instructional features with fidelity features is that it obscures the unidimensional definition of utility. One solution would be to perform two separate analyses: one that defines utility in terms of fidelity features, and the other, in terms of instructional features. The attributes for the

---

<sup>4</sup>The fact that P-COFT was rated higher for movement subtasks would appear anomalous because it does not allow full control of movement. Note that control of movement was indeed the most important attribute for this set of subtasks. However, this positive aspect of SIMNET was not able to overcome its deficiencies with respect to other attributes that were judged important to movement: of particular note is SIMNET's failure to simulate defilade positions, degraded gunnery, machine guns, and battlefield obscuration. Each of the latter features was supported by P-COFT. Finally, it should be noted that, because the simulated tanks in P-COFT move independently along parallel tracks, the movement techniques and some formations (e.g., wedge and line) can be executed by controlling the relative speeds of the tanks.

<sup>5</sup>PRIME originally was designed to be equipped with the Tank Weapons Gunnery Simulation System (TWGSS), a precision gunnery simulator. Delays in development of TWGSS prevented its being implemented in the present version of MILES.

latter analysis would be the individual features themselves. There exist several inventories of instructional features (e.g., Sticha, Singer, et al., 1988) that could be used to generate appropriate attributes for the analysis. The analyst could use results from both analyses to reach a final conclusion. The problem would occur when the fidelity-based and instructional features-based analyses come to substantially different conclusions. In that case, the user could treat the two utilities as attributes in another MAUT analysis, weight them accordingly, and reach a final solution. The central point to this discussion is that instructional features of devices can be treated exactly like fidelity features in a MAUT-based analysis to select devices.

The second difficulty with the MAUT-based model was that the analysis only examines utilities while ignoring costs. On a cost basis, the computer-based alternatives (SIMNET and P-COFT) would clearly be preferred because they incur no OPTEMPO resources as do the tank-appended devices. However, as discussed in the methods section, there are cost elements other than OPTEMPO. Assuming that device costs could be comprehensively identified, cost-utility analyses (Levin, 1985) could be performed to compare device selections on the basis of costs, utility, or with both factors considered. However, a systematic consideration of costs would clearly complicate the device selection procedure considerably.

#### Structure/Sequence Instruction

There is little systematic precedent for the application of sequencing principles to military training, and there exists virtually no empirical literature comparing the *outcomes* of different training sequences. Nevertheless, it is instructive to illustrate the use of sequencing principles derived from the general literature of the psychology of learning as reviewed in the methods section. As a first approximation to systematic sequencing, further simplifications are proposed in order to illustrate the application of these sequencing principles to a representative set of armor activities.

Several of the sequencing principles summarized in Table 3 can be eliminated without serious loss, for the following reasons. First, a number of the principles derived from differing contexts have essentially the same import, and some have no application in the present context. Thus rules 2.1, 2.2, and 2.3 (comprising the Natural order category)--while distinguishable in a fine analysis--convey a message similar to 5.2 (Natural sequence). Principle 5.2 is also approximated by 1.2 (Subject logic) at some levels, but the distinction will be preserved for application to subtasks. Again, item 3.3 (Practice different modes) will have almost the same impact upon armor training as 6.1 (Vary practice). With respect to item 4.1 (Transfer order), too little information is available on transfer of training to allow deductions to be drawn. Another item, 5.1 (Overlapping practice) may be ruled out of consideration on the grounds that the principle addresses the sequencing problem at a different level, affecting the integration of units rather than the order in which the units are presented for training. As an outcome of these considerations, it is possible to provide the following residual list of nine principles:



- 1.1 Teach ends before means.
- 1.2 Follow the logic of the subject matter.
- 1.3 Use progressive elaboration.
- 3.1 Move from slow to fast practice.
- 3.2 Move from orientation, through practice, to real task.
- 4.2 In general, progress from easy to difficult.
- 5.2 Follow the natural sequence of the task.
- 6.1 Vary practice between training devices.
- 6.2 Provide real equipment experience early in training.

It must next be decided at what levels the sequencing principles should be put into practice. To illustrate the application of these rules, it was useful to first structure the list of platoon collective training objectives as an organized hierarchy. The analysis by Morrison et al. (1990) suggested that the 19 subtasks were best grouped into the eight task groupings. However, as shown in Figure 8, further analysis showed that certain clusters may be combined to form superordinate units. Thus, although group 1 (Travel in platoon formation) and group 2 (Execute battle drills) were already sufficiently comprehensive, groups 3 (Bound), 4 (Overwatch), 5 (Occupy), and 6 (Maneuver) could all be considered instances of the more general category concerned with "Field position." Again, group 7 (Fire patterns) and group 8 (Firing techniques) could both be treated as variants of a general "Firing" category. Furthermore, it appeared that the four resulting categories might be grouped into two broad classifications. The combination of group 1 (Travel) together with the new category of "Field position" could be regarded as a broad category representing "Movement;" the combination of group 2 (Battle drills) with the new category "Firing" constituted the broad category "Engagement". Hence, it was possible to depict the platoon subtasks in the form of the hierarchy as shown in Figure 8.

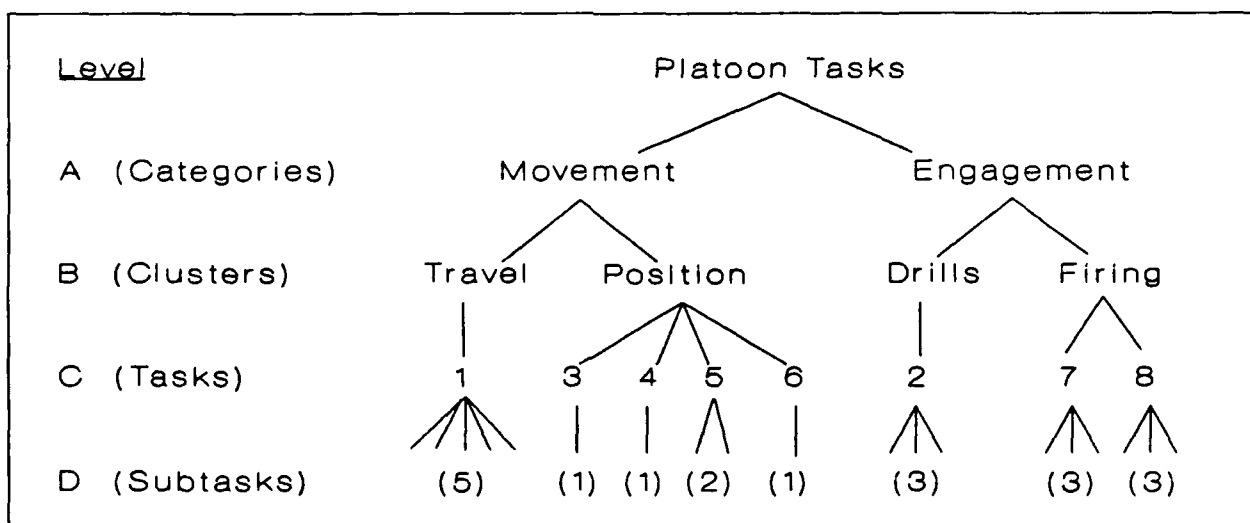


Figure 8. Hierarchical arrangement of platoon collective subtasks.

Sequence higher level elements (categories and clusters). With reference to Figure 8, the sequencing problem was considered at each of the levels A, B, C, and D. However, it appears that few of the sequencing principles were readily applied to the upper levels of the hierarchy. At level A, the only question was whether Movement (M) should precede or follow Engagement (E). Since Engagement could be considered the end in relation to Movement as the means, principle 1.1 (Ends before means) apparently recommended the order E -> M. Principle 1.2 (Subject matter logic) appeared only applicable to sequencing within units, as was largely true of several other principles (1.3. Progressive elaboration; 3.1. Slow-to-fast; 3.2. Orientation-practice-real). However, given the assumption that Movement is a less difficult task than Engagement, application of principle 4.2 (Easy-to-difficult) yielded the order M -> E; the same order was implied by principle 5.2 (Follow natural sequence), assuming that Movement normally precedes Engagement. At this level (A), principle 6.1 (Vary devices) seemed equally satisfied by the orders M -> E or E -> M.

Before considering the application of principle 6.2 (Real equipment experience), it was necessary to recall the results of the device utility ratings listed earlier. In general, the ratings suggested that the principal devices were almost equally valuable for tasks 1 through 6, although SIMNET is somewhat less useful on many subtasks. However, P-COFT was notably superior for task 7 (Fire patterns), with Subcaliber as next most suitable; these rankings remained very similar for task 8 (Firing techniques). In assigning devices to training units, it was assumed that the principal devices for training in tasks 7 and 8 is the P-COFT and Subcaliber devices, with greater flexibility available in tasks 1-6. However, with respect to principle 6.2 (Real equipment), it should be remembered that there may be training utility in tank exercises not connected with any device, which might be inserted into the earlier tasks (1-6). The simplest interpretation might be that category E, which contains tank practice in the form of Subcaliber, should precede category M training. However, the Subcaliber device was marginally the most effective in most of the Movement tasks, so that there was insufficient evidence to warrant reversing the M -> E order.

The sequencing procedure appeared somewhat inconclusive at this level, but the results became clearer with further progress down the hierarchy. The outcomes of applying the selected sequencing principles at level A are listed in Table 9, as are those for the following level (B). As an example of the arguments at this intermediate level, consider the implications of principle 4.2 (Easy-to-difficult). The decision at level A to place M before E implied that Travel (T) and Position (P) clusters should be less difficult than the Drills (D) and Firing (F) clusters. Within each grouping, T appeared simpler than P, and D appeared simpler than F. Hence, the order T -> P -> D -> F was recorded in Table 9. Other decisions followed similar lines, as shown in the body of the table. The consensus at the second level (B) appeared to favor the partial order T -> P -> D, although it was unclear whether F should have preceded or followed the other components. As a temporary expedient, it was assumed that the order T -> P -> D -> F is primary, with F remaining in last place. The problem raised by principle 6.2 (real equipment), which tentatively placed cluster F in first place, was handled by ensuring that the devices recommended for training cluster T (Travel) occur first and include real tank experience in some form (perhaps using the Subcaliber device, as noted above). Note that the deferment of firing practice, a basic skill, was

only possible here on the assumption that platoon training had been preceded by earlier gunnery practice. A further complication was that principle 1.1 (Ends before means) appeared to be at odds with all of the later principles. A compromise solution was to drop 1.1 from the main analysis, but to hold the principle in reserve for use as necessary to resolve ties between the remaining set of principles.

Table 9

Application of Sequencing Principles at Higher Levels of the Hierarchy

Level	Order	Principle								
		1.1	1.2	1.3	3.1	3.2	4.2	5.2	6.1	6.2
A	1	E	-	-	-	-	M	M	-	M
	2	M					E	E		E
B	1	F	-		-	-	T	T	-	F
	2	D		T			P	P		T
	3	P		P			D	D		P
	4	T					F	F		D

Note. E = engagement; M = movement; D = drills; F = firing; P = positioning; T=travel. A dash (-) indicates that the principle has no apparent application.

Sequence lower level elements (tasks and subtasks). Decisions were then made at the next lower level (C), where the eight main task types had to be ordered. The ordering was first made on the basis of the Travel -> Position -> Drills -> Firing sequence adopted at the higher level, but was then reconsidered regardless of the prior order to find whether the procedure has introduced any anomalies. The starting order of tasks within clusters therefore became: (T) 1, (P) 3 4 5 6, (D) 2, (F) 7 8 .

Next, training devices were provisionally assigned to tasks in order to evaluate compliance with principles 6.1 (Vary devices) and 6.2 (Real equipment). Reviewing the ratings assigned above to device utility, for example, showed that task 1 was best served by the Subcaliber device (S), or else by P-COFT (C) or MILES (M). After device C, task 2 was best served by M or by PRIME (P). Table 10 shows the highest ranking devices for each task, together with a suggested choice based on making some use of all the principal devices (C, M, P, S) so as to ensure that principle 6.1 (Vary devices) was satisfied. Since there were many ties among the utility ratings, many other device selections would have been almost equally acceptable. It was assumed that SIMNET (N) would also be introduced from time to time to provide variety of practice.

Table 10

## Assignment of Devices to Tasks in Clusters

Cluster	<u>Travel</u>	<u>Position</u>				<u>Drill</u>	<u>Firing</u>	
Task	1	3	4	5	6	2	7	8
Ranked devices	S	M	C	S	S	C	C	C
	C	P	M	C	C	M	S	
	M		P	M		P		
Assigned	S	P	C	C	S	M	S	C

Note. Letters refer to devices: C = P-COFT; M = MILES; P = PRIME; S = Subcaliber. Numbers denote tasks within clusters: 1 = travel; 2 = drills; 3 = bound; 4 = overwatch; 5 = occupy; 6 = maneuver; 7 = patterns; 8 = techniques.

The starting order for tasks 1 through 8, suggested by the above application of the principles of sequencing to levels A and B of the hierarchy, was summarized as laid out in the first row of Table 11. Next, each principle was applied in succession to ordering the tasks that constitute level C of the hierarchy. The method consisted of first making successive modifications to the orders of tasks, while preserving the order of task clusters. It should be noted that no algorithm existed for deciding the order in which to apply the sequencing principles. The method adopted was to consider each principle in the order originally derived, using its application to make any appropriate changes to the immediately prior ordering. Where any principle had no application, the order was simply left unchanged. All of the resulting modifications are listed in Table 11. It can be seen that, at least in this instance, very few changes in order were enjoined by the successive application of the different sequencing principles. In addition, the table shows that the final order presented an acceptable variety of devices that included early practice on tank-mounted devices. The most difficult practical decisions were occasioned by principles 3.1 (Slow-fast) and 4.2 (Easy-difficult) as applied to tasks 2 (Drills), 7 (Fire patterns), and 8 (Firing techniques). The order 8 -> 7 -> 2 appeared almost equally good, but this sequence contradicted the decision earlier in the hierarchy to place F after D. The chosen final order, as represented in the table, therefore reflected the earlier decision. However, the problem raised the question whether the same final sequence would be recommended if the higher-order categorization were to be disregarded.

Although the decisions regardless of clustering at the higher level were made independently, it was inevitable that applying the same considerations produces similar order. Note, however, that the results might be similar but not identical. For example, although cluster P as a whole precedes clusters D and F, the effect might have been due to the influence of tasks 3 (Bound), 5 (Occupy), and 6 (Maneuver); task 4 (Overwatch) could arguably be relocated on

the basis of principles 3.1 (Slow-fast) or 4.2 (Easy-difficult). In fact, however, constructing a new table by applying the same procedures used in Table 11 while disregarding the cluster structure produced identical results for the platoon collective tasks. It was therefore superfluous to reproduce the second table.

Table 11

Task Orders Resulting from Successive Modifications Within Clusters

Principle	Tasks in Order							
Starting Order	1	3	4	5	6	2	7	8
1.2	1	3	4	5	6	2	8	7
1.3	1	4	3	5	6	2	8	7
3.1	1	4	3	5	6	2	8	7
3.2	1	4	3	5	6	2	8	7
4.2	1	4	3	5	6	2	8	7
5.2	1	4	3	5	6	2	8	7
6.1	1	4	3	5	6	2	8	7
6.2	1	4	3	5	6	2	8	7
Devices	M	P	M	S	C	P	C	S

Note. Letters refer to devices: C = P-COFT; M = MILES; P = PRIME; S = Subcaliber. Numbers denote tasks within clusters: 1 = travel; 2 = drills; 3 = bound; 4 = overwatch; 5 = occupy; 6 = maneuver; 7 = patterns; 8 = techniques.

The next problem was to resolve the sequence of subtasks, at level D of the hierarchy, within the tasks ordered above. Tasks 3 (Bound), 4 (Overwatch), and 6 (Maneuver) each consisted of only one subtask. Hence, it was only necessary to sequence within the remaining tasks 1 (Travel), 2 (Drills), 5 (Occupy), 7 (Fire patterns), and 8 (Firing techniques). These were considered in the order chosen above in Table 11 (1, 5, 2, 8, 7). Applying sequencing principles to these series of subtasks gave rise to the results listed in Table 12. Successive modifications are not shown in detail, since the applicable principles appeared to generate similar orders.

The final step is to complete the assignment of device support to subtasks. There was sufficient variety at the subtask level to justify making direct use of the utility ratings. Table 13 summarizes the final order of subtasks, associating each with the devices ranked first and second in utility. The tabulation demonstrates that there was ample scope for providing training on a variety of supporting devices.

Table 12

## Final Orders for Subtasks Within All Platoon Collective Tasks

Task	Subtask Order				
1. Travel	1.5 Column	1.3 Line	1.2 Echelon	1.4 Vee	1.1 Wedge
4. Overwatch	4.0 Overwatch				
3. Bound	3.0 Bound				
5. Occupy	5.1 Initial		5.2 Subsequent		
6. Maneuver	6.0 Maneuver				
2. Drills	2.1 Action		2.2 Contact		2.3 Air
8. Techniques	8.1 Observed		8.3 Simult		8.2 Altern
7. Patterns	7.1 Frontal		7.3 Depth		7.2 Cross

The final ordering summarized in Table 13 embodies virtually all of the sequencing recommendations discussed above. In so far as the principles are applicable, the sequence follows the logic of the subject matter (principle 1.2) and uses progressive elaboration (1.3). Wherever possible, the training moves from slow to faster practice (3.1). In keeping with most training practices, the sequence progresses from easy to difficult tasks (4.2). Training in the recommended order follows the natural sequence of the platoon functions (5.2), thus concurrently preserving job performance order (2.1), chronological sequence (2.2), and critical sequences (2.3). The recommended training sequence confers an appreciable amount of variety of practice (6.1), thus facilitating the generalization necessary for efficient transfer of training. Finally, as evidenced by Table 13, the training schedule will offer opportunities for practice on the real equipment early in the training sequence (6.2), thus providing for the establishment of appropriate cognitive models and correcting for failures in device fidelity.

Table 13

## Training Recommendations Using Ordered Subtasks with Assigned Device Support

Order	Subtask		Training Device	
	Number	Title	Primary	Secondary
1	1.5	Execute a Column/Staggered Column	Subcaliber	P-COFT
2	1.3	Execute a Line Formation	MILES	P-COFT
3	1.2	Execute an Echelon Formation	Subcaliber	P-COFT
4	1.4	Execute a Vee Formation	P-COFT	MILES
5	1.1	Execute a Wedge Formation	Subcaliber	P-COFT
6	4.0	Overwatch a Bounding Platoon	P-COFT	MILES
7	3.0	Bound by Section	MILES	PRIME
8	5.1	Occupy Initial Battle Position	MILES	P-COFT
9	5.2	Occupy Subsequent Battle Position	Subcaliber	P-COFT
10	6.0	Maneuver Within a Battle Position	Subcaliber	P-COFT
11	2.1	Execute Action Drill	MILES	PRIME
12	2.2	Execute Contact Drill	P-COFT	MILES
13	2.3	Execute Air Attack Drill	Subcaliber	P-COFT
14	8.1	Employ Observed Fires	P-COFT	Subcaliber
15	8.3	Employ Simultaneous Fires	P-COFT	MILES
16	8.2	Employ Alternating Fires	P-COFT	Subcaliber
17	7.1	Employ Frontal Fire	P-COFT	Subcaliber
18	7.3	Employ Depth Fire	P-COFT	Subcaliber
19	7.2	Employ Cross Fire	P-COFT	Subcaliber

Summary and Conclusions

The application of methods for designing a training strategy demonstrated, in general, that the various methods could be applied to dissimilar gunnery training problems with sensible results. Only one of the methods failed to apply to both problems: The methods for allocation of training time were only applicable to the simpler gunnery training problem where only two training devices were considered; the methods for allocating training time were not well-suited for the more difficult multi-task, multi-device tactical training problem. The problem was not in the mathematics: The mathematical methods for allocating training time described by Cronholm (1985) and Sticha, Singer et al. (1988) could have been extended to the multi-task, multi-device allocation problem. Rather, the problem was that data requirements of such methods exceeded that which could be reasonably obtained. Clearly, no performance data exist for this complex problem, leaving simulated transfer data as the only alternative. To obtain simulated transfer data, experts would have been required to make numerous demanding judgments about the capabilities of training devices, some of which exist only in prototype form, to train subtasks for which there are no clear-cut standards of performance. The resulting data collected under those conditions would be virtually meaningless and incongruent with their treatment by sophisticated mathematical techniques.

As reflected in the detailed results from this applications section of the report, differences between the problems were noted in the level of effort

required to apply the methods. For instance, it was considerably more difficult to apply the instructional sequencing methods to the second tactical problem than to the first problem involving basic gunnery skills. The reason for this difference was simply the greater number of objectives in the second problem which led to a much greater number of possible sequences. Consequently, the sequencing rules were applied in a more systematic manner in the second compared to the first problem to insure overall adherence to the rules. On the other hand, the instructional structuring methods were more complex for the first than for the second problem. The cause of this difference appeared to be the fact that the first problem dealt with "smaller" objectives that were more likely to be related to one another than the tactical objectives in the second problem. Analogous to the previous case, the approach taken was to be systematic and consider all relations among objectives.

The fact that there were differences between problems in exact methodology argues that fully developed algorithms cannot, at the present time, be developed for the instructional sequencing and structuring strategies. The appendix addresses this problem indirectly by suggesting systematic procedures for using the heuristics related to structuring and sequencing instruction. However, there may be some benefit in the methods remaining somewhat undetermined so that the user can tailor them to his or her particular training application. On the other hand, without algorithmic procedures, there is no guarantee that different users will arrive at identical training strategies. However, if different strategies were obtained from appropriate application of the methods, the users would be assured that both would be in accord with basic training principles. In this regard, the outcome from the application of a heuristic can be seen to be different than that from an algorithm: Heuristic methods do not necessarily provide the user with a single "optimal" strategy; rather, they provide basic guidance for developing a strategy that adheres to known training principles.

Although the training strategy methods were discussed and applied independently, there are many points at which they interact. For instance, organizing objectives affects the sequencing of those objectives and vice versa. Reigeluth and Curtis (1987) argued that, because of these interactions, "... strategy components should not be prescribed individually; instead, they should be combined into optimal models ... for different learning situations" (p. 177). Such models are starting to appear. For instance, the model for Optimization of Simulation-Based Training Systems (OSBATS) is concerned with the training device design and use (Sticha, Blacksten, et al., 1988). The present concern, in contrast, is with the use of existing devices for training and testing purposes. More in line with the present purposes, Blacksten (1989) provided the outline of an integrated model of media selection that is based on learning and transfer functions. The outcome not only selects the media, but allocates training time as well. Both approaches are mathematically complex and have substantial data requirements. Furthermore, it is arguable whether or not the current knowledge of training processes can support such sophisticated optimal models. The present approach, which summarizes this knowledge in heuristic and algorithmic guidelines, is perhaps an intermediate point in developing such an integrated model. As these components are applied and empirically tested, an integrated model for developing training strategies may eventually emerge.



## References

- Adams, J. A. (1960). Part trainers. In G. Finch (Ed.), Educational and training media: A symposium (Publication No. 78, pp. 129-149). Washington, DC: National Academy of Sciences-National Research Council.
- Apter, M. J. (1970). The computer simulation of behavior. New York: Harper Colophon Books.
- Ash, D. W. (1987). Part versus whole training: Task separation and reintegration. Unpublished doctoral dissertation, the University of Louisville.
- Ash, D. W., & Holding, D. H. (in press). Backward versus forward chaining in the acquisition of a keyboard skill. Human Factors.
- Bailey, J., Hughes, R. G., & Jones, W. E. (1980). Application of backward chaining to air-to-surface weapons delivery training (AFHRL-TR-79-63). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.
- Bandura, A. (1986). Social foundations of thought and action: A social cognitive theory. Englewood Cliffs, NJ: Prentice-Hall.
- Bickley, W. R. (1980). Training device effectiveness: Formulation and evaluation of a methodology (ARI Research Report 1291). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A122 777)
- Blacksten, H. R. (1989). An OSBATS-based approach to training media/devices selection. Unpublished manuscript. Human Resources Research Organization, Alexandria, VA.
- Boldovici, J. A. (1987). Measuring transfer in military settings. New York: Academic Press.
- Boldovici, J. A., Harris, J. H., Osborn, W. C., & Heinecke, C. L. (1977). Criticality and cluster analyses of tasks for the M48A5, M60A1, and M60A3 tanks (ARI Technical Report TR-77-A17). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A048 607)
- Braby, R., Henry, J. M., Parrish, W. F., & Swope, W. M. (1975). A technique for choosing cost-effective instructional delivery systems (TAEG Report No. 16). Orlando, FL: Department of the Army, Training Analysis and Evaluation Group.
- Branson, R. K., Rayner, G. T., Cox, J. L., Furman, J. P., King, F. J., & Hannum, W. H. (1975). Interservice procedures for instructional systems development. Fort Eustis, VA: U.S. Army Transportation School.
- Campbell, D. T., & Stanley, J. C. (1966). Experimental and quasi-experimental designs for research. Chicago: Rand McNally.

- Campbell, R. C., & Campbell, C. H. (1990). Methodology for defining and sampling from the domain of threat conditions for crew and platoon tactical gunnery (ARI Technical Report 886). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A221 094)
- Carter, G., & Trollip, S. (1980). A constrained maximization extension to incremental transfer effectiveness, or, how to mix your training technologies. Human Factors, 22, 141-152.
- Colley, A. M. (1989). Cognitive motor skills. In D. H. Holding (Ed.), Human skills (2nd ed.). London: John Wiley & Sons, Ltd.
- Cronholm, J. N. (1985). The optimization of training systems. Proceedings of the Symposium on the Transfer of Training to Military Operational Systems (pp. 237-259). Brussels, Belgium: NATO.
- Doyle, E. L. (1990). Threat presentations for selected battlefield scenarios (ARI Research Product 90-14). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A221 289)
- Drucker, E. H., Campbell, R. C., Koger, M. E. & Kraemer, R. E. (1989). Observations made during an on-site visit to the Phantom Run (WP FTKNOX 89-2). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.
- Drucker, E. H., & Morrison, J. E. (1987). The development of a single tank tactical exercise for training M1 tank commanders (ARI Research Report 1443). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A189 482)
- Edwards, W. (1987). Decision making. In G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley.
- Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.), Categories of human learning. New York: Academic Press.
- Friendly, M. (1979). Methods for finding graphic representations of associative memory structures. In C. R. Puff (Ed.), Memory organization and structure. New York: Academic Press.
- Gagné, R. M. (1967). Instruction and the conditions of learning. In L. Siegel (Ed.), Instruction: Some contemporary viewpoints. San Francisco: Chandler.
- Gagné, R. M. (1984). Learning outcomes and their effects: Useful categories of human performance. American Psychologist, 39, 377-385.
- Glaser, R., Lesgold, A., Lajoie, S., Eastman, R., Greenberg, L., Logan, D., Magone, M., Weiner, A., Wolf, R., & Yengo, L. (1986). Cognitive task analysis to enhance technical skills training and assessment (Contract No. F41689-83-C-0029). Pittsburgh: Learning Research and Development Center, University of Pittsburgh.

- Gray, W. D., & Orasanu, J. M. (1987). Transfer of cognitive skills. In S. M. Cormier & J. D. Hagman (Eds.), Transfer of learning. New York: Academic Press.
- Hannaman, D. L. (1984). Specifying battle simulation requirements: A model and case history (HumRRO Professional Paper 2-84). Alexandria, VA: Human Resources Research Organization.
- Harris, J. H., Osborn, W. C., & Boldovici, J. A. (1977). A paired comparison approach for estimating task criticality. Paper presented at the Military Testing Association, San Antonio, TX.
- Hoffman, R. G., Drucker, E. H., Morrison, J. E., & Goldberg, S. L. (1983). Memory organization-based methods of instruction (HumRRO Final Report FR-TRD(KY)-83-6). Alexandria, VA: Human Resources Research Organization.
- Hoffman, R. G., Fotouhi, C. H., Meade, G. A., & Blacksten, H. R. (1990). Methods for designing threat-based gunnery tests (HumRRO Final Report FR-PRD-90-10). Alexandria, VA: Human Resources Research Organization.
- Hoffman, R. G., & Morrison, J. E. (1988). Requirements for a device-based training and testing program for M1 gunnery: Volume 1. Rationale and summary of results (ARI Technical Report 783). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A194 808)
- Hoffman, R. G., & Witmer, B. G. (1989). Development of a Unit-Conduct of Fire Trainer (U-COFT) test of M1 gunnery proficiency (ARI Technical Report 859). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A219 045)
- Holding, D. H. (1965). Principles of training. London: Pergamon.
- Holding, D. H. (1976). An approximate transfer surface. Journal of Motor Behavior, 8, 1-9.
- Holding, D. H. (1977). Transfer of training. In B. B. Womans (Ed.), International encyclopedia of psychiatry, psychology, psychoanalysis, and neurology (pp. 268-272). New York: Van Nostrand.
- Holding, D. H. (1987). Concepts of training. In G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley.
- Holland, J. G. (1960). Teaching machines: An application of principles from the laboratory. In A. A. Lumsdaine & R. Glaser (Eds.), Teaching machines and programmed learning. Washington, DC: National Education Association.
- Knerr, C. M., Morrison, J. E., Mumaw, R. J., Stein, D. J., Sticha, P. J., Hoffman, R. G., Buede, D. M., & Holding, D. H. (1986). Simulation-based research in part-task training (AFHRL Technical Report 86-12). Brooks AFB, TX: Air Force Human Resources Laboratory.

- Knerr, C. M., Morrison, J. E., Mumaw, R. J., Sticha, P. J., Blacksten, H. R., Harris, C., & Lahey, G. (1987). Analysis and design of part-task training for aircrew skills (HumRRO Draft Final Report 87-2). Alexandria, VA: Human Resources Research Organization.
- Kribs, H. D., Simpson, A. C., & Mark, L. J. (1983). Automated instructional media selection (AIMS) (Tech. Rep. NAVTRAEQUIPCEN 79-C-0104-1). Orlando, FL: Naval Training and Equipment Center.
- Levin, H. M. (1985). Cost-effectiveness: A primer. Beverly Hills, CA: Sage Publications.
- Lintern, G., Roscoe, S. N., & Sivier, J. E. (1989). Display principles, control dynamics, and environmental factors in pilot performance and transfer of training. Proceedings of the Fifth International Symposium on Aviation Psychology, Columbus, OH.
- Lintern, G., Sheppard, D. J., Parker, D. L., Yates, K. E., & Nolan, M. D. (1989). Simulator design and instructional features for air-to-ground attack: A transfer study. Human Factors, 31, 87-99.
- Mackay, D. G. (1982). The problems of flexibility, fluency, and speed-accuracy tradeoff in skilled behavior. Psychological Review, 89, 483-506.
- Mané, A. M., Adams, J. A., & Donchin, E. (1989). Adaptive and part-whole training in the acquisition of a complex perceptual-motor skill. Acta Psychologica, 71, 179-196.
- Mané, A. M., Coles, M. G. H., Karis, D., Strayer, D., & Donchin, E. (1984). The design and use of subtasks in part training and their relationship to the whole task (NASA Conference Publication 2341). In S. G. Hart & E. J. Hartzell (Eds.), Twentieth Annual Conference on Manual Control. Moffett Field, CA: National Aeronautics and Space Administration.
- Mané, A. M., Coles, M. G. H., Wickens, C. D., & Donchin, E. (1983). The use of the additive factors methodology in the analysis of skill. Proceedings of the 27th Annual Meeting of the Human Factors Society (pp. 407-411). Santa Monica, CA: Human Factors Society.
- McCormick, E. J., & Bachus, J. A. (1952). Paired comparison ratings. Journal of Applied Psychology, 36, 123-127.
- Merrill, P. F. (1987). Job and task analysis. In R. M. Gagné (Ed.), Instructional technology: Foundations. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Metzko, J. (1987). Simulation trainers for tank gunnery (IDA Paper P-1973). Alexandria, VA: Institute for Defense Analyses.
- Morris, N. M., & Rouse, W. B. (1985). Review and evaluation of empirical research in troubleshooting. Human Factors, 27, 503-530.
- Morrison, J. E. (1984). Methods for empirically deriving the structure of memory for procedures. Journal of Applied Psychology, 69, 473-481.

- Morrison, J. E. (1985). Guidebook for analysis and design phases of course revision (ARI Research Product 85-18). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A160 452)
- Morrison, J. E. (1988). Power analysis of gunnery performance measures: Differences between means of independent groups (HumRRO Special Report SP-PRD-88-10). Alexandria, VA: Human Resources Research Organization.
- Morrison, J. E., & Goldberg, S. L. (1982). A cognitive analysis of armor procedural tasks training (ARI Technical Report 605). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A139 795)
- Morrison, J. E., & Hoffman, R. G. (1988). Requirements for a device-based training and testing program for M1 gunnery: Volume 2. Detailed analyses and results (ARI Research Product 88-03). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A196 365)
- Morrison, J. E., Meade, G. A., & Campbell, R. C. (1990). Identification of tactical gunnery subtasks: Objectives for a threat-based training program (HumRRO Final Report FR-PRD-90-03). Alexandria, VA: Human Resources Research Organization.
- Morrison, J. E., & Walker, S. A. (1989). The effects of mental practice on tank gunnery performance (HumRRO Interim Report IR-PRD-89-10). Alexandria, VA: Human Resources Research Organization.
- Naylor, J. C. (1962). Parameters affecting the relative efficiency of port and training methods: A review of the literature (NAVTRADEVCEEN 950-1). Port Washington, NY: U.S. Naval Training Device Center.
- Osgood, C. E. (1949). The similarity paradox in human learning: A resolution. Psychological Review, 56, 132-143.
- Pfeiffer, M. G., & Horey, J. D. (1988). Analytic approaches to forecasting and evaluating training effectiveness (Technical Report 88-027). Orlando, FL: Naval Training Systems Center.
- Pouvenmire, H. K., & Roscoe, S. M. (1973). The incremental transfer effectiveness of a ground-based general aviation trainer. Human Factors, 15, 534-542.
- Reigeluth, C. M., & Curtis, R. V. (1987). Learning situations and instructional models. In R. Gagné (Ed.), Instructional technology: Foundations. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Resnick, L. B. (1976). Task analysis in instructional design: Some cases from mathematics. In D. Klahr (Ed.), Cognition and instruction. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Roscoe, S. N. (1971). Incremental transfer effectiveness. Human Factors, 14, 561-567.

- Roscoe, S. N., & Williges, B. H. (1980). Measurement of transfer of training. In S. N. Roscoe (Ed.), Aviation psychology. Ames, IA: The Iowa State University Press.
- Ryder, J. M., Beckchi, R. G., Redding, R. E., & Edwards, B. J. (1988). Modern training model concepts for aircrew training (AFHRL-TR-87-34). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.
- Salmoni, A. W. (1989). Motor skill learning. In D. H. Holding (Ed.), Human skills (2nd ed.). London: John Wiley & Sons, Ltd.
- Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. Psychological Review, 82, 225-260.
- Singer, R. N. (1968). Sequential skill learning and retention effects in volleyball. Research Quarterly, 39, 185-194.
- Sticha, P. J., Blacksten, H. R., Buede, D. M., Singer, M. J., Gilligan, E. L., Mumaw, R. J., & Morrison, J. E. (1988). Optimization of simulation-based training systems: Model description, implementation, and evaluation (HumRRO Final Report 88-26). Alexandria, VA: Human Resources Research Organization.
- Sticha, P. J., Singer, M. J., Blacksten, H. R., Morrison, J. E., & Cross, K. D. (1988). Research and methods for simulation design: State of the art (HumRRO Final Report 88-27). Alexandria, VA: Human Resource Research Organization.
- Tufano, D. R., & Evans, R. A. (1982). Army prediction of training device effectiveness: A review of Army models (ARI Technical Report 613). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A146 937)
- Turnage, J. J., & Bliss, J. P. (1989). Training transfer in a tank gunnery training system. Proceedings of the 33rd Annual Meeting of the Human Factors Society. Santa Monica, CA: Human Factors Society.
- Vineberg, R., & Joyner, J. N. (1980). Instructional system development (ISD) in the armed services: Methodology and application (HumRRO Technical Report 80-1). Alexandria, VA: Human Resources Research Organization.
- Westra, D. P. (1982). Investigation of simulator design features for carrier landing: II. In-simulator transfer of training (NAVTRAEQUIPCEN 81-C-0105-1). Orlando, FL: Naval Training Equipment Center.
- White, R. T. (1973). Research into learning hierarchies. Review of Educational Research, 43, 361-375.
- Wickens, C. D. (1989). Attention and skilled performance. In D. H. Holding (Ed.), Human skills (2nd ed.). London: John Wiley & Sons, Ltd.

- Wightman, D. C. (1983). Part-task training strategies in simulated carrier landing final approach training (NAVTRAEQUIPCEN IH-347). Orlando, FL: Naval Training Equipment Center.
- Wightman, D. C., & Lintern, G. (1985). Part-task training for tracking and manual control. Human Factors, 27, 267-283.
- Williges, R. C., & Baron, M. L. (1973). Transfer assessment using a between-subjects central-composite design. Human Factors, 15, 311-319.
- Witmer, B. G. (1988). Device-based gunnery training and transfer between the Videodisk Gunnery Simulator (VIGS) and the Unit Conduct of Fire Trainer (UCOFT) (ARI Technical Report 794). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A197 769)
- Wolfle, D. (1951). Training. In S. S. Stevens (Ed.), Handbook of experimental psychology. New York: John Wiley.

## Appendix

### Methods and Materials for Structuring and Sequencing Training

As discussed in the main body of the report, the methods for selecting devices and allocating training are relatively well-developed algorithms. In contrast, the methods for structuring and sequencing training are presented as a set of heuristic guidelines. Some of the guidelines were based on well-established research findings and training practices, while others were based on some recent theorizing. Despite the tentative nature of the guidelines, it is still possible to specify how they might actually be used; the purpose of this appendix is to do just that. The present methods are presented in this appendix instead of the body of the report, because they are unprecedented and untried. Nevertheless, this initial scheme provides the bare-bones outline of a method from which more algorithmic procedures may be developed. Development of the present procedures are discussed below in terms of three related issues: (a) the information requirements of the methods, (b) the format of the input data, and (c) the use of the output data.

#### Information Requirements

As discussed in the text, the guidelines for structuring and sequencing training require detailed knowledge about training concepts and methods. It is assumed that the user of the present methods is an experienced training designer who would him/herself play the role of training methods expert. The other requirement is detailed knowledge of the task domain being trained, that is, armor gunnery. The topics of gunnery and gunnery training have become increasingly technical and specialized in recent years. As a result, it is unreasonable to expect the training designer to have the specialized knowledge to execute the methods. In that case, the designer must rely on input from subject matter experts (SMEs). One specific purpose of the present appendix is to specify more clearly the required input of SMEs.

The process of specifying SME input began with the identification of those guidelines where their input would be most helpful. Table 14 summarizes the heuristic guidelines that were presented in the text of the report, and indicates whether or not useful input can be obtained from a training methods expert or from an SME. As shown in the table, both types of expertise are appropriate to most of the guidelines. The only cases where SMEs do not would not have an obvious role in providing information are those guidelines that relate to the specification of training conditions. Also, some of these rules come into play later in the training design process, that is, after training devices have been chosen. Nevertheless, this initial analysis suggests that the SME can provide significant input to the application of these guidelines.

#### Format for SME Input

The next issue is what format the SME input should take. One approach used in the training development literature is to have experts provide numerical ratings of the elements of the instruction. For instance, SMEs typically provide numerical ratings of the criticality of training objects; these ratings are the used to arrange training priorities within a course of instruction. This quantitative approach allows the training designer to



Table A-1

## Sources of Information for Structuring and Sequencing Principles

<u>Training Strategy Problem</u>	<u>Source of Information</u>	
	<u>Training Methods Expert</u>	<u>Subject Matter Expert</u>
<u>Guidelines</u>		
<u>Structure Training Objectives</u>		
A pair of objectives should be trained together given that one of the following conditions is met:		
● one objective is dependent on the other (i.e., it has the other as a prerequisite);	YES	YES
● one objective supports the other (i.e., it transfers to the other);	YES	YES
● both objectives are sequentially related and share a common task subgoal; or	YES	YES
● both objectives are time-shared and share a common attentional resource.	YES	YES
<u>Sequence Training</u>		
Sequence training according to the following guidelines:		
● Teach ends before means	YES	NO
● Follow the logic of the subject matter	NO	YES
● Use progressive elaboration	YES	YES
● Move from slow to fast practice	YES	NO
● Move from orientation, through practice, to real task	YES	NO
● In general, progress from easy to difficult	YES	YES
● Follow the natural sequence of the task	NO	NO
● Vary practice between training devices	YES	NO
● Provide real equipment experience early in training	YES	NO

easily aggregate the input from multiple SMEs by calculating measures of central tendency (e.g., the mean, median, or mode). These quantitative ratings also allow the designer to measure the agreement among the various raters. In that regard, it should be noted that interrater reliability is a necessary (but not sufficient) condition for valid ratings. One problem with this approach is that people are not typically very reliable in their subjective ratings of individual objects. For instance, interrater reliability for rating the criticality of individual tasks is poor; however, reliability substantially improves when they are asked to make relative judgments of *pairs* of objects (Harris, Osborn, & Boldovici, 1977).

To the extent possible, this paired comparison format was used in the proposed methods. That is, paired comparison items were developed to correspond to those guidelines wherein SME input was identified as relevant. For some of those guidelines, however, a paired comparison format was deemed inappropriate; for those, absolute ratings were developed. The attachment to this appendix presents both the paired comparison and individually rated items in the form of a worksheet that SMEs can use to provide their input.

With respect to the paired comparisons, two points should be noted. First, there is a potential problem in the number of judgments required by the paired comparisons approach. For  $k$  objects, there are  $k(k - 1)/2$  possible comparisons. That means that, for a list of 100 objectives for instance, there would be 4,950 pairs that must be rated. In those cases where the numbers of to-be-rated pairs is unreasonable for an individual judge to manage, the partial paired comparison method can be used wherein individual raters provide judgments on selected subsets of the total numbers of to-be-rated pairs. McCormick and Bachus (1952) showed that a partial paired comparison approach can be used without serious degradation in reliability. Second, some items are not "pure" paired comparison in the sense that the rater is not presented a forced choice of one object over the other. Sometimes the ratings are on some continuous scale. For example, two of the items require the rater to judge the amount of transfer that would occur from one objective to the other in the pair. Even though such items do not use a forced choice format, the paired comparison format is useful in isolating the pairwise relationships that exist among the objectives.

The worksheet items are clustered into groups that relate to specific concepts discussed in the text of the report. These concepts are explained to the raters using examples with which they should be familiar. If the SME were to rate many objectives or objective pairs, it might be advantageous to devise separate instructions and response sheets. These groups of conceptually related items are explained below, and their implications for training are briefly noted.

1. Prerequisiteness. Items 1a and 1b concern the concept of prerequisiteness. Items related by prerequisiteness should be trained in close proximity to minimize forgetting and interference effects. Also the prerequisite must be trained *prior* to superordinate objectives.

2. Transfer among objectives. Objectives that are related by transfer should be kept close together to minimize forgetting and interference effects. As discussed in the text, however, transfer relationships do not have clear implications for the sequencing of training. Items 2a and 2b require the SME

to predict the transfer, in terms of time savings, that would occur from one member of the pair to the other.

3. Interference of simultaneous activities. Items 3a - 3c pertain only to individual crewman's activities that can be performed together. If the pair of activities interfere with one another, they should be trained together so that the performer learns appropriate time-sharing skills. If they are not interfering, they could be trained apart (if need be). [This concept of interfering simultaneous activities is also addressed in 7 below, but in a more theoretical context.]

4. Job performance order. The purpose of Item 4 is to ascertain the sequential relationships that exist between activities corresponding to a pair of training objectives. The implication is that, if such sequential relationships exist on the job, they ought to be maintained in training.

5. Ease of learning/performance. Items 5a and 5b pertain to the relative ease of the two objectives. The first item of this group pertains to the ease of learning the objective, whereas the second relates to the ease of performing the activities that correspond to the objective. All other factors being equal, training on an easier objective should precede the training of a more difficult one.

6. Common subgoals. The first of the individual ratings pertains to the guidance that objectives related to a common subgoal should be trained together. If the domain were not already divided into subgoals, one possible approach is to have SMEs sort objectives into piles--the Q-sort technique--to discover any implicit goal structure in the domain (Glaser et al., 1986). Morrison (1984) presented a method for analyzing the proximity of recalled elements for revealing the implicit goal structure of procedural tasks. However, it is more likely that as that the training objectives have been derived through an analysis of domain subgoals (Morrison, et al., 1990). If that be true, the more expeditious approach would have SMEs confirm this explicit structure by identifying which objectives are associated with the subgoals that have been identified.

7. Attentional resources. Item 7 is designed to supplement Items 3a-3c by describing the objective with respect to Wickens's (1989) "resource space." As discussed in the text, this space is used to predict the extent to which two simultaneously performed activities can be time-shared. The items pertain to the three dimensions of the resource space: stage of processing, modality of processing, and type of response. The general prediction from this model is that two activities that require common levels on a dimension will suffer greater interference than two that demand separate levels.

#### Use and Integration of SME Information

As stated earlier, the training methods expert may want to make him/herself available during the SME input to answer questions that may come up--particularly with regard to some of the more abstract concepts discussed above. In that regard, a workshop of SMEs and the training methods expert may facilitate the interchange between the two types of experts, and aid the training expert in providing his/her input.

Once the input is obtained, the next question is how to apply the guidance. The guidelines were not designed to be applied in any particular order; rather, training designers should use the information from the SMEs and their own knowledge to construct tentative configurations to fit those guidelines. Morrison (1985) suggested using index cards to represent each objective and trying to arrange the course's configuration so that it is maximally congruent with guidelines. This process is viewed as an iterative procedure wherein the designer successively resequences and restructures the course to achieve better and better congruency with the whole set of guidelines.

Because these methods are new and untested, they should be the focus for continuing research and development. One area of development might be to treat the SME data to more sophisticated analyses than described above. For instance, the degree to which pairs of objectives are interfering can be used as proximity data in a multidimensional analysis of task components. The result would provide an empirically derived structural model of attentional resources. It would be of both theoretical and practical interest to examine the degree to which this solution corresponds to Wickens's (1989) resource space.

## Attachment to the Appendix

### Worksheet for SME Ratings

#### Paired Comparisons

The following questions concern the following two training objectives:

Objective A: Title.....
Objective B: Title.....

#### Prerequisiteness

The first rating issue relates to the necessity of learning one objective before starting to learn the other. For instance, we must learn to walk before we can learn to run. In terms of academic skills, we must learn to count before we can learn addition.

QUESTION	RESPONSE
1a. Is it <u>necessary</u> to know A before B can be learned?	YES    NO    (Circle one)
1b. Is it <u>necessary</u> to know B before A can be learned?	YES    NO    (Circle one)

#### Transfer

Although it may not be necessary to learn one objective before another, having learned one objective may nevertheless be helpful to learning another. By "helpful," we mean that having learned one objective will actually speed up learning on the second. For instance, it is not necessary to learn to drive a car before learning to drive a truck; however, a person who already knows how to drive a car will learn truck driving more quickly than a person who has never driven a car.

The following ratings are in terms of the percent of time required: If X does not help at all, enter 0; if X reduces the time required by half, enter 50; if X reduces the time required by three-quarter, enter 75; and so on.

QUESTION	RESPONSE
2a. Rate the percent of <u>time saved</u> learning B after having learned A to standard.	_____ (0-100 percent)
2b. Rate the percent of <u>time saved</u> learning A after having learned B to standard.	_____ (0-100 percent)

### Interference of Simultaneous Activities

Some tasks can sometimes be performed simultaneously. For instance, a pilot often must use the radio while flying his aircraft. The following questions require you to indicate whether or not the activities described by A and B can be performed simultaneously.

QUESTION	RESPONSE
3a. Can the activities corresponding to A and B be performed simultaneously?	<input type="checkbox"/> YES (Answer 3b-3d) <input type="checkbox"/> NO (Go to 4)

If you answered YES to 3a, rate the degree to which performance one activity degrades performance on the other. If one activity completely disrupts the other, enter 100%; if one activity degrades performance by half, enter 50%; if one activity has no effect on the performance on the other, enter 0%.

QUESTION	RESPONSE
3b. Is it possible that A and B can be performed at the same time?	YES   NO   (Circle one)
3c. If response to 3a is YES, rate the degree to which performance of A degrades performance of B.	_____ (0-100 percent)
3d. If response to 3a is YES, rate the degree to which performance of B degrades performance of A.	_____ (0-100 percent)

### Sequential Relationships

On the job, the activities related to one objective may precede the activities of another. For example, learning to change a tire might could be decomposed into two training objectives: using the jack to raise the car, and removing the wheel and tire. Clearly, the former objective usually precedes the second. Another possibility is that the two objectives may not be sequentially related. For instance, there is no necessary sequential relationship between learning to change a tire and learning to shift gears.

QUESTION	RESPONSE
4. Describe the sequential relationship that exists between the activities in objectives A and B.	<input type="checkbox"/> A normally occurs before B <input type="checkbox"/> B normally occurs before A <input type="checkbox"/> A and B are not sequentially related (Check one)

### Ease of Learning and Performance

The next group of items concern the relative ease of the two objectives. Item 5a asks you to identify which of the two objectives is easier to learn, whereas item 5b asks which is easier to perform.

QUESTION	RESPONSE
5a. Of the two objectives, which is the easier to learn?	<input type="checkbox"/> Objective A <input type="checkbox"/> Objective B (Check one)
5b. Once learned, which of the two is easier to perform?	<input type="checkbox"/> Objective A <input type="checkbox"/> Objective B (Check one)

### Individual Ratings

Objective A: Title.....

#### Subgoals

Tasks are performed for a reason. These reasons are called task goals and subgoals. For instance, raising a automobile with a jack could be classified as a task. However, it is performed with some specific goal in mind (e.g., to change a tire). Similarly, we have identified the general subgoals to which the activities corresponding to objectives could be addressed.

QUESTION	RESPONSE
6. Identify which of the subgoals Objective A addresses.	<input type="checkbox"/> Subgoal 1 <input type="checkbox"/> Subgoal 2 <input type="checkbox"/> Subgoal 3 <input type="checkbox"/> Subgoal 4 : : :

#### Resource Space

Tasks can be described with respect to their mental demands. The demands can be stated in terms of three dimensions: stage of processing, sensory modality, and type of responses. For instance, "issue fire command" would be classified as involving primarily central processing, using both visual and auditory modalities, and requiring a vocal (as opposed to manual) response. Using the response alternatives provided below, describe Objective A with respect to these three dimensions.

QUESTION	RESPONSE
7a. Describe the objective with respect to "stage of processing"	<input type="checkbox"/> encoding (i.e., perception, recognition) <input type="checkbox"/> central processing (i.e., memory, cognition) <input type="checkbox"/> overt responding
7b. Describe the objective with respect to sensory modality	<input type="checkbox"/> vision <input type="checkbox"/> audition
7c. Describe the objective with respect to type of responses	<input type="checkbox"/> manual <input type="checkbox"/> vocal